WEST VIRGINIA
GEOLOGICAL SURVEY

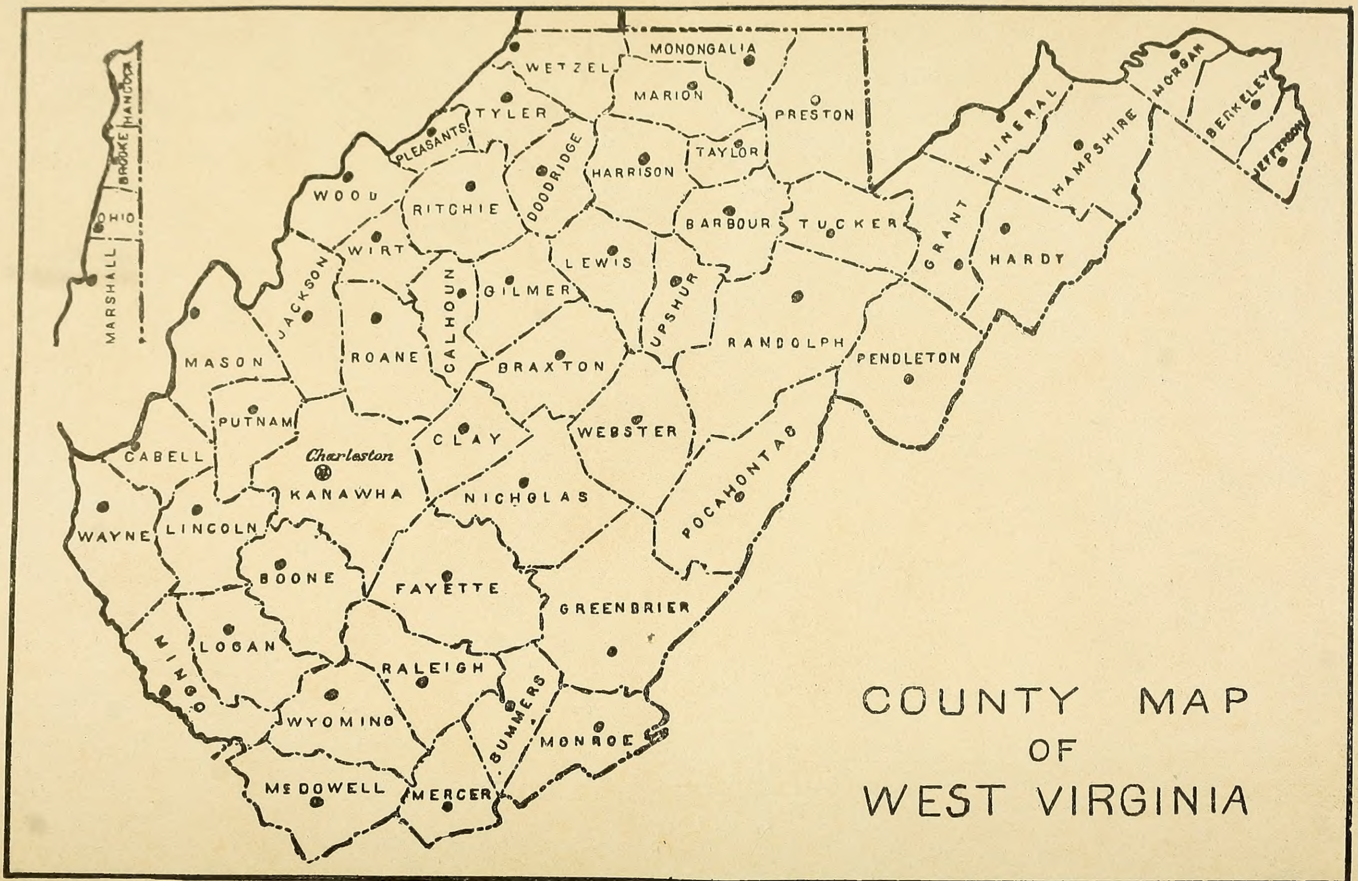

Plate I.—Outline County Map of West Virginia.

WEST VIRGINIA
GEOLOGICAL SURVEY

VOLUME FOUR

Iron Ores, Salt and Sandstones

BY

G. P. GRIMSLEY

I. C. WHITE, State Geologist

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LETTER OF TRANSMITTAL.

To His Excellency, Hon. Wm. E. Glasscock, Governor of West Virginia and President of the Geological Survey Commission:

SIR: I have the honor to transmit herewith the Report of Prof. G. P. Grimsley on Iron Ores, Building Stones, Salt, etc., constituting Volume IV. of the series designed to cover the entire state in a general way. Prof. Grimsley has given much labor and time to the preparation of this report, and it speaks for itself concerning the thoroughness, and success with which he has completed the task assigned to him. This volume will soon be followed by two Detailed County Reports, viz: that of Mr. Ray V. Hennen on Marshall, Wetzel and Tyler Counties which is now passing through the press, and that of Prof. G. P. Grimsley on Pleasants, Wood and Ritchie which will soon be ready for printing. Bulletin No. 2, by the State Geologist, on Levels Above Tide, and giving many new oil and gas well records from the recently developed fields, will also be published and issued during the present year.

Very respectfully,

I. C. WHITE,
State Geologist.

Morgantown, July 1, 1909.

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PREFACE.

As in volume III, so in the present volume, a group of mineral resources is described which at the present time shows a small development; but gives promise of valuable future additions to the wealth of the state. The future of the iron ore supply is now attracting marked attention on the part of the iron and steel companies. The time is not far distant when the great Lake Superior district cannot supply the demand and new fields must be opened. It is one of the objects of this report to show that West Virginia offers a promising field for this development and to draw the attention of these companies to this district.

From 1800 to 1880 West Virginia was an iron ore producing state, and small furnaces here and there over the state were making pig iron from native ores with profit, but at the present time this ore is not mined. Most of these old furnaces worked the thin (10 to 18 inches) seams of carbonate ores in the coal measures, with 20 to 27 per cent metallic iron. It is not generally known that richer and heavier bodies of ore of long extent are to be found along the eastern border. A study of this report will prove that they do exist and in quantity to justify most careful exploitation.

These ores chemically were unsuited to manufacture of Bessemer steel, and as long as practically all the American steel was made by this process, iron ore in West Virginia had little or no value. In recent years there has been great progress in the steel industry with a rapid development of open hearth steel manufacture which now surpasses Bessemer steel in quantity of output. The West Virginia ores are suitable for this steel and therefore have become valuable. Further south in Tennessee, Alabama, etc., similar ore deposits are rapidly passing under the control of large companies. The lack of railroad transportation in these mountain counties has so far held back the development of these ores, but this present summer will probably see the extension of

a railroad into western Hardy and southern Grant counties, and other roads will doubtless follow. The time is at hand for capital to examine the iron ore claims of these mountain counties not yet reached by a railroad.

Very little information has been available on the West Virginia iron ores, and it is hoped that the present volume will to some extent supply this need and show the great possibilities of a future iron ore industry. The results of our investigations show that there are large surface exposures of iron ore of good quality in the state, but the lack of core drilling prevents any reliable estimates as to depth of ore as a basis for tonnage calculations. In a few of the counties we have attempted to make conservative estimates of tonnage based on available data. In Pendleton county, for example, this estimate is about 30,000,000 tons; in Hardy and Hampshire counties, 75,000,000 tons; in Greenbrier and Pocahontas, 35,000,000 tons.

The United States mining over 51,000,000 tons annually is the leading iron ore country of the world, with a total production almost double that of Germany the next country in rank, and three times that of Great Britain. It is even predicted by competent authorities that in the next ten years, the American production of steel will be doubled. This means greater demand for iron ore and will require the opening and development of new ore lands and new districts, and should in natural course of the industry result in the establishment of an iron ore industry in this state.

The relation of open-hearth to Bessemer steel industry involves a technical discussion which may be found in many standard treatises on Metallurgy. It was thought best to include in the present report a brief non-technical description of the methods of manufacture of iron and steel based on a number of these treatises cited in the text, which forms chapter IV. The chapter on fuels and fluxes shows that we have within the borders of the state all the materials for iron and steel manufacture, including coke from a number of different fields, and limestone of the highest quality in the country. The iron ore deposits of the dif-

ferent counties are described with complete chemical analyses made in the Survey laboratory. The concluding chapter of this part shows the relation of West Virginia to the general iron ore industry.

Part II of this report treats of the salt industry which was one of the leading industries in the state down to 1878, but it has rapidly declined on account of the cheaper manufacture with stronger brines in Michigan and New York. The present industry at Malden, Hartford City, and Mason City, has survived on account of the special properties of this salt and the presence of the valuable by-products of bromine and calcium chloride. More attention should be paid to the uses of calcium as given in this report. There should be a greater demand for this material in the state for good roads and the many other uses almost unknown to our people.

In volume III the limestones of the state were described and their uses and development discussed. In the present volume in part III, the sandstones are treated in similar manner. The quarry industry in this state is much smaller than it should be, and the information is here available as to location of the sandstone quarries, their development, quality of the stone, and other data. We have building stone equal in quality, color, strength, to the various quarry products shipped into the state from other places, and we should be able to supply demands in other sections.

It was intended to include a very complete series of physical tests on these different quarry sandstones, and arrangements were made for this work with the U. S. War Department at the Watertown, Mass., arsenal; but after the work was well started, Congress voted to move the testing plant to Washington, and our work was interrupted. The material was later sent to the U. S. Geological Survey testing plant at St. Louis, and again by order of removal of this plant to Pittsburg the work has been temporarily stopped. As it will be some months before the tests can be completed, it was deemed best to issue this report without further delay and without the complete physical tests which will appear in a later publication.

The writer is under obligation to many people in the preparation of this volume, and it is impossible to name all of them. In Hardy county the ore belts were followed through the mountains by the aid of two valuable local guides. Jonah Thorpe and Henry Orendorff. The data on early furnaces in that area was furnished by Messrs. Volney and DeVan Keller, owners of the Capon Furnace property. On my last trip to that area I was accompanied by Mr. Raphael Pumpelly, a geologist of wide experience whose suggestions proved most helpful. In the Greenbrier county area valuable assistance was rendered by Mr. John Fulton, the well known mining engineer of Johnstown, Pa.

In the collection of data on the salt industry, Mr. J. R. Dickinson of Malden and Mr. Smith of the Liverpool Salt Co., at Hartford have aided in various ways. In the study of the sandstones we were fortunate to secure the assistance of Mr. S. L. Powell, post graduate student in Johns Hopkins University who made the microscopial study of the thin sections included in this report. The various quarry companies have aided our work in furnishing data, and many of them prepared and sent the stone samples for the physical tests, and it is a matter of regret that the unavoidable delays in this work have prevented the full publication of the tests in this volume.

The very complete and careful chemical analyses through this report have been made by Prof. B. H. Hite, chief chemist and his assistant Mr. Leicester Patton. Plates for illustration have been loaned by the Engineering and Mining Journal and by Prof. J. A. Bownocker of the Ohio Geological Survey. The writer is under special obligation to Dr. I. C. White, State Geologist, for his kindly help and criticism of the subject matter of the report.

G. P. GRIMSLEY.

Martinsburg, W. Va., June 15, 1909.

PART I.

The Iron Ores of West Virginia.

CHAPTER I.

IRON AND ITS COMPOUNDS.

Iron is one of the most abundant elements in the rocks of the earth's crust, ranking fourth in quantity acording to the determinations of F. W. Clarke, of the U. S. Geological Survey, as given in the following table:

Oxygen.....49.98	per	cent	Iron..........5.08	per	cent
Silicon......25.30	"	"	Lime.........3.51	"	"
Aluminum .. 7.26	"	"	Magnesium...2.50	"	"

Limestone, sandstone, shales, clays, and the various types of igneous rocks all contain iron. All waters, salt and fresh, contain this element. Its distribution is therefore world wide and it occurs in rocks of all geological groups and subgroups.

Iron is rarely found in the earth's rocks in a pure or native state. The only large masses of native iron known in the earth's crust are in the basalts (volcanic rocks) near Ovifak, Greenland. It also occurs in practically all meteorites where it is alloyed with nickel. While of mineralogical interest, native iron has no economic importance.

The valuable ores of iron in the world are compounds of iron with various chemical elements forming the following varieties:

Oxides......	Magnetite (Fe_3O_4)
	Hematite (Fe_2O_3)
	Limonite ($Fe_2O_3+nH_2O$) or brown hematite
Carbonate..........	Siderite ($Fe\ CO_3$)
Sulphide............	Pyrites (FeS_2)
Sulphate............	Copperas ($Fe\ SO_4 + 7\ H_2O$).

Iron is also found in combination with a great variety of elements forming the various iron minerals, but these are not of economic importance as sources of iron.

The important iron ores used as sources of metallic iron are the oxides and carbonate, which, when theoretically pure yield the following percentages of metallic iron:[1]

	Percentage of metallic iron.	Yield in pounds of metallic iron per ton of theoretically pure ore.
Magnetite	72.4	1,448
Hematite	70	1,400
Limonite	59.8	1,196
Siderite	48.2	964

The ores are never found pure in nature but are mixed with various other chemical compounds, which lower the theoretical yield of the ores, as shown in the following analysis of one of the West Virginia limonites, which, if absolutely pure, would contain 59.8 per cent of metallic iron.

	Per cent.
Metallic iron	48.18
Silica	16.40
Manganese	0.02
Sulphur	0.13
Phosphorus	0.43

In addition to the chemical impurities, a portion of which are shown in the above incomplete analysis, there are various foreign substances present in the ores, as clay, sand, rock fragments, which tend to further lower the yield of metallic iron per ton of ore as taken from the mine.

[1] Dana, Text Book of Mineralogy.

The value of an iron ore depends in part upon the percentage of metallic iron, but even more on the nature and effect of the impurities present. Some of the impurities are inert, some are injurious, while others may be beneficial in the iron for certain uses. The study of the character and reactions of the foreign material in iron ores thus becomes a most important subject, and must be thoroughly understood before the real value of a given ore can be determined.

In the earlier days of the iron industry the good and bad characters of iron ores were often known without understanding the cause. Certain ores could be worked at a profit in the old charcoal furnaces, while other ores, in the same region, were found to be of no value when tested, although by the eye little or no difference could be detected. No attempt was made to determine the causes of the different reactions, but the so-called bad ores were left in the ground, while other ores farther and farther away from the furnace were mined. Later study of such discarded deposits has revealed the presence of chemical impurities which rendered the ore unfit for use in the old style furnace, while often by modern methods of mixing and treating the ores, they have been found valuable.

In order to understand more clearly the nature of iron ores, available in West Virginia, brief descriptions of the different kinds of iron ores mined in the United States will be given.

MAGNETITE (Fe_3O_4).

Magnetite, or magnetic iron ore, receives its name from its magnetic properties, acting as a natural magnet. Chemically it is regarded as a combination of two oxides of iron: the ferrous, or protoxide, FeO, and the ferric, or sesquioxide, Fe_2O_3, in proportion of 31 per cent of the former to 69 per cent of the latter. When theoretically pure it contains 72.4 per cent metallic iron, and 27.6 per cent oxygen. The ferrous oxide may be partially replaced by magnesium or by titanium.

Magnetite is the ore of the large iron mines in Norway and Sweden. It is found in large masses in Archaean gneisses

and crystalline limestones in the Adirondacks and other localities in northern New York, in North Carolina, Michigan, Wisconsin, Virginia, and the Cornwall mine in Pennsylvania.

The Cornwall mine is one of the large iron mines of the United States, and the largest outside of the Lake Superior district. It has been operated since 1732, producing to the close of 1906 over 17,000,000 tons of ore. Up to 1893 it was the largest producing iron mine in this country and in 1906 ranked 12th with a production of over 800,000 tons. The ore is low in phosphorus and runs 40 to 55 per cent metallic iron.

Magnetite is found in lenticular masses through northeastern Pennsylvania and in Franklin and Henry counties of Virginia. It is mined in New York, New Jersey, Pennsylvania, and North Carolina. Of the total iron ore mined in the United States in 1906[2], 5.2 per cent was magnetite, and 7.4 per cent of the ore mined in the past 18 years was magnetite. It thus ranks third in importance among the iron ores in this country.

Magnetite sometimes carries titanium in such quantities as to render the ore of no value. Some of the Adirondack ores carry 15 per cent and many deposits carry as high as one per cent. Such deposits are not worked at the present time. Titanium does not injure the quality of the iron, but renders the ore more infusible, therefore requiring more fuel and greater cost in smelting.

Franklinite is a magnetite with the iron partially replaced by manganese and zinc and is found at Franklin Furnace, New Jersey, where it is associated with zinc silicate and oxide in granular limestone.

HEMATITE (Fe_2O_3).

Hematite is distinguished from magnetite by its red streak and lack of magnetic properties, while magnetite leaves a black streak. At the present time it is the great source of iron,

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[2] Eckel U. S. Geol. Survey, Mineral Resources for 1906.

comprising 89 per cent of the iron ore mined in the United States in 1906, and according to Eckel, 81.5 per cent of the iron ore mined in this country during the past 18 years was hematite, as compared with 7.4 per cent magnetite and 10.6 per cent limonite.

The bright crystalline variety of this ore is known as specular hematite, which sometimes is marked by a brilliant display of colors, as seen in the island of Elba ores now practically exhausted . The ordinary dull ore is the red hematite, and the loose earthy material is called ocher and occurring in red and yellow colors, is used for paint. A few examples of well known hematite deposits are given to illustrate the general character of this group of ores.

Clinton Iron Ores. In the Clinton formation of the Upper Silurian rocks there is found in many places a red hematite horizon in the shales and limestones, well exposed in Wisconsin, Ohio, Kentucky, New York, Pennsylvania, Virginia, West Virginia, Tennessee, Georgia, Alabama. The ore is often filled with casts of shells and crinoids forming the red fossil ore, while again it is made up of rounded grains forming the red oolite ore. The Clinton ores are sometimes high in lime passing below into a limestone. The thickness of the ore in Wisconsin is 12 to 25 feet. At the type locality, Clinton, New York, there are two ore beds, an upper two foot vein, separated by a foot of shale from a lower eight inch bed.

According to Kemp,[3] the Clinton ores become important in Juniata district of Pennsylvania, and the belt extends southwest across Maryland, Virginia and West Virginia, thence across eastern Tennessee where they are important ores. They outcrop in northwestern Georgia and again in Alabama, where they are especially important and with the less productive Siluro-Cambrian limonites furnish practically all the iron ore of Alabama. Their close association in that state, with coal and limestone forms a most favorable field for development, so that Alabama now holds third rank in the production of iron ore.

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[3] Ore Deposits, p. 104.

The Clinton red hematite in Alabama is interbedded with red sandstones and shales. A section of the Eureka mine at Oxmoor as made by C. H. Smyth, Jr., shows the following order of strata:[4]

	Feet.
Red sandstone	5
Yellow sandstone	6
Red sandstone	15
Soft Clinton red hematite	2
Hard ore	20
Shale	6
Rich ore	2½

It is further stated the outcrop of this ore can be traced almost continuously for 130 miles.

The Clinton ores are often designated as hard and soft, referring to differences in composition. The surface ore, more or less, leached of lime, shows a higher percentage of iron and in places is somewhat loose and porous so that it has been called the **soft ore** and may vary in thickness from a few inches to several feet. Below the soft ore is the so-called **hard ore** which still retains its lime and therefore shows a lower percentage of iron. The Clinton ores are usually high in lime and also in phosphorus, the latter preventing their use for Bessemer iron. At Clinton, New York, the ore averages 44 per cent metallic iron in furnace runs.

LAKE SUPERIOR DISTRICT. The largest deposits of hematite ores in this country are found in the Lake Superior district in northern Michigan, Wisconsin, and Minnesota. There are in this area five principal ore belts, or ranges, which are listed in the following table of Eckel, showing location, date of development and production for a period of 18 years:[5]

[4] Quoted from Kemp. Ore Deposits, p. 105.

[5] U. S. Geol. Survey, Mineral Resources for 1906, 1907.

RANGE	LOCATION	OPENED	PRODUCTION 1889-1906 in long tons	PRODUCTION 1907 in long tons
Marquette	Upper Peninsula Michigan near Lake Superior	1824	54,091,441	4,167,810
Menominee	Upper Peninsula Michigan southern border, and Wisconsin	1872	50,308,316	4,779,592
Gogebic	Northwest border Up. Peninsular Michigan ..	1884	47,532,521	3,609,519
Vermilion	Minnesota northwest of Lake Superior	1884	24,064,820	1,724,217
Mesabi	Minnesota northwest of Lake Superior	1892	123,513,206	27,245,441
Total			299,510,304	41,526,579

Two varieties of ore are shipped from the Marquette range, known as the hard and soft, the former is shipped in lumps and the latter as small gravel like masses of dirt and mined with steam shovel. The soft ores are found in synclinal basins below a quartzite conglomerate, while the hard ores form lenses in the conglomerate. Mining of these Lake Superior ores began in 1854 and a little over 100,000 tons were produced in 1860. The production in 1890 reached nearly 9,000,000 tons; in 1900, it was 20,564,238 long tons according to U. S. Geological Survey, and in 1906 reached 37,876,371 long tons.

The Menominee and Penokee iron ores are soft earthy hematite, while the ores of the Vermilion range are hard specular hematites. The Mesabi range of Minnesota, opened in 1893, furnishes blue and brown soft ores.

The ore bearing rock of the Mesabi range rests on a quartzite which is unconformable on the green schists. The ore rock is a jaspery chert overlaid by greenish siliceous slate, cherts and large masses of gabbro rock.[6]

[6] Kemp. *loc. cit.* p. 128.

Missouri. At Pilot Knob (600 feet high) in Missouri,[7] two beds of hard specular hematite are found separated by a seam of slate and interstratified with breccias and sheets of porphyry. The lower bed, 25 to 40 feet thick, has furnished most of the ore which is a bluish specular hematite with 50 to 60 per cent iron and low phosphorus. The upper bed is irregular and of lower grade. It is 6 to 60 feet thick and is now practically exhausted.

Iron Mountain, five or six miles north of Pilot Knob, contains veins of hard specular hematite irregularly seaming a knob of porphyry, while on the slopes of the hill are sedimentary rocks, the lowest member of which is a conglomerate of ore fragments and weathered porphyry, forming the principal source of the ore mined.

LIMONITE ($Fe_2O_3+n\ H_2O$).

Limonite is chemically ferric iron like hematite plus 10 to 14 per cent of water. It is found in a variety of colors, mostly brown or yellow, and leaves a yellowish brown streak. It is found in form of pipes, stalactites, fibrous masses, concretionary and nodular ores, and in beds or strata. Its distribution is more wide spread than the other two types, but its percentage of metallic iron is lower, and the percentage of impurities is usually higher. It is often called brown hematite and in total production ranks next to red hematite, but only includes 5.8 per cent of total iron ore mined in this country as compared with 89 per cent of red hematite.

Bog iron ore is a variety of limonite found in marshes and swamps. It is a rough, brown ore more or less porous, and earthy. It often contains rootlets, leaves and wood fiber, and occurs in the shallow beds or nodular masses with a low percentage of metallic iron.

Siluro-Cambrian limonites according to Kemp. (p. 88) extend along the Appalachian Mountains from Vermont to Alabama in clays. The deposits at Salisbury, Connecticut, are quite large and were among the first iron ores worked in

[7] Kemp. Ore Deposits, p. 132.

this country. This group of limonites has been mined in Lehigh and York counties in eastern Pennsylvania and across Maryland in Carroll and Frederick counties, also in the Shenandoah Valley of West Virginia and Virginia. They have been opened in eastern Tennessee, northwestern Georgia, and become very important in Alabama. They run 40 to 50 per cent metallic iron, but are usually too high in phosphorus for Bessemer work.

Oriskany Ores. The Oriskany sandstone of the Devonian often carries in the Appalachian area important deposits of limonite ore, mined at Longdale, Low Moor, Oriskany, etc., in western part of Virginia, where they average 40 to 43 per cent iron.

The Virginia brown ores, according to Eckel,[8] are not original deposits in the Oriskany sandstone but are replacements of the Helderberg limestone and adjacent beds of the Oriskany. The formations in the Oriskany ore districts are given by Eckel as follows:

	Thickness in feet.
Devonian black shales	1,000—2,000
Oriskany sandstone and siliceous limestone	50— 250
Helderberg limestone	300— 800
Clinton shale and sandstone	300— 600
Medina quartzite	50— 150

The rocks have been thrown into a series of parallel folds with N. 35° E. trend and erosion of softer beds has left the harder rocks to form the crests of the ridges while the slopes are covered by the softer strata. The ores range from 32 to 36 per cent of metallic iron with high silica. Eckel gives the following analysis of the Lowmoor furnace ore as fairly representative of these ores:[9]

[8] Eckel U. S. Geol. Survey, Bull. 285, p. 183.
[9] *loc. cit.* p. 187.

Silica	33.26
Alumina	5.26
Ferric iron oxide	52.86
Manganese oxide	0.61
Lime oxide	0.28
Sulphur	0.014
Phosphorus (P_2O_5)	1.312
Carbon dioxide	0.21
Water	1.90

SIDERITE ($FeCO_3$).

Siderite, spathic iron, or carbonate of iron when theoretically pure contains 48.2 per cent metallic iron and 37.9 per cent carbon dioxide and has a brown to brownish red color while its streak is white. The ore is usually impure by admixture of magnesium, lime and various other ingredients, changing its color and lowering the percentage of iron, and the deposits are as a rule small in thickness and often limited in extent. Siderite includes only 5-10 of one per cent of the total iron ore mined in the last 18 years with a total of a little over 2,000,000 tons. The production has been declining from year to year and in 1906 was about 18,000 tons.[10]

In the earlier days of the iron industry the carbonate ores were worked at numerous places in the eastern and central portions of the United States, forming an important source of supply for the furnaces, many of which depended wholly on this ore.

Concretionary iron carbonate masses known as clay ironstone containing lime, magnesium, clay and a low percentage of iron, are found in shales at a number of horizons, especially in the Coal Measures. While at the present time such ore has no value, yet in past years furnaces were built to work these small and irregular deposits. One of the earliest iron furnaces in West Virginia was built at Clarksburg to use the so-called ball ore in the shales below the Pittsburg coal.

Carbonate of iron beds containing bituminous matter are called *black-band ores,* and in some deposits the lime was sufficient to flux the ore, with nearly enough bituminous matter to furnish the necessary fuel. While the percentage

[10] Eckel, *loc. cit.*

of iron was low, these deposits, on account of the useful impurities, were profitably worked for many years. The centers of carbonate iron ore mining were in Kentucky, Ohio, Pennsylvania and West Virginia, but most of these deposits have been exhausted or abandoned. A few small furnaces here and there still mine a small quantity of carbonate ores.

PYRITES ($Fe S_2$).

Iron pyrites is found in all geological horizons and in nearly all localities. It is one of the most common minerals and while usually found in small quantities, large deposits are known and some of these mined. The mineral usually has a golden yellow color and is mistaken by many people for gold or other valuable metals so that it is often termed "fools gold."

When pure, pyrites contains 46.6 per cent iron and 53.4 per cent sulphur. It is used at a few places as a source of sulphur in the manufacture of sulphuric acid. Attempts to extract the iron after the removal of the sulphur have not been very successful. The value of small deposits of this mineral is nothing.

The relative importance of the iron ores mined in the United States in 1906 and 1907 is shown in the following table from U. S. Geological Survey:

	1906.	1907.	Period of 19 years.
Hematite	89.0 per cent	89.1	82.4
Limonite	5.8 " "	5.7	10.1
Magnetite	5.2 " "	5.2	7.1
Carbonate			0.4

IMPURITIES IN IRON ORES AND THEIR EFFECTS.

Iron ore is not found in nature in the theoretical pure form yielding the percentages of metallic iron indicated by the chemical formulae. The percentage of iron is lowered

by the presence of chemical and mechanical impurities, some of which seriously interfere with the economic value of the ores.

CHEMICAL IMPURITIES.

Titanium or Titanic Acid. Titanic acid is found in appreciable quantities only in the magnetites, and when over one per cent is present, it is regarded as harmful, while with over three per cent the ores are seldom mined or worked at the present time. Titanium increases the infusibility of the slag and results in a loss of iron through the slag. It also, according to Nitze, forms troublesome accretions of hard, infusible nitrocyanide of titanium on the furnace hearth, which in time necessitates a new hearth. The increase in infusibility requires more fuel and therefore higher cost, while the loss of iron through the slag lowers the yield of the ores, so that titaniferous magnetites are looked upon with disfavor and under present prices and conditions are seldom worked.

Phosphorus. This element is one of the most troublesome and injurious impurities in iron ores. Small percentages render the iron brittle when cold, and the ores are known as *cold-short*.

Iron has a very strong affinity for phosphorus, so it cannot be separated in the blast furnace and this element remains in the pig iron. Further, any phosphorus present in the fuel or flux will pass into the pig iron and not into the slag. When such pig iron is treated in the acid Bessemer converter, the phosphorus remains in the steel. The maximum allowable limit of phosphorus in ordinary steel is 1-10 of one per cent. Iron ores are therefore classified on basis of phosphorus content into Bessemer and non-Bessemer ores. Phosphorus is usually determined in analysis as phosphoric acid P_2O_5 and the percentage of phosphoric acid divided by 2.29 will give the percentage of phosphorus.

A Bessemer iron ore is one in which the percentage of phosphorus in the pig iron made from it will not exceed 1-10 of one per cent. To obtain this maximum limit of phosphorus

in a given iron ore, Kemp gives a very simple rule;[11] divide the percentage of iron in the ore by 1,000 and the result is the maximum phosphorus limit in a Bessemer ore. Thus, if the ore contains 52.6 per cent of iron, the minimum limit of phosphorus would be .0526 per cent.

Nitze[12] used the phosphorus ratio to determine the limit; that is, the amount of phosphorus in 100 parts of metallic iron, which he illustrates as follows: If an ore contained 60 per cent metallic iron and 0.03 per cent phosphorus, then 60 per cent in ore: 100 per cent in pig iron:: 0.03 per cent phosphorus in ore: x per cent phosphorus in the pig iron, or

$$\frac{100}{60} = \frac{x}{0.03} \quad x = \frac{100 \times .03}{60} = 0.05 \text{ per cent.}$$

while 0.10 per cent represents the allowable limit.

According to Keep[13] phosphorus produces a very peculiar grain in cast iron, giving a flat fracture with each grain standing clear and alone, apparently with low cohesion among the particles which probably explains the brittleness of phosphorus iron, the color of the fracture is white with a tendency to straw color, and such iron is always light in color (Keep).

Phosphorus lowers the shrinkage of cast iron. Keep states that probably no element of itself weakens cast iron so much as phosphorus when present in quantity over 1.5 per cent; and it probably does not affect the hardness of the iron, but slightly increases its fluidity.

According to H. H. Campbell[14], phosphorus up to 0.12 per cent strengthens steel, but in the rolling mill it tends to produce coarse crystallization and so lowers the temperature to which it is safe to heat the steel, requiring great care in working. In steel for tools and cutlery, phosphorus is especially objectionable as it makes the steel difficult to temper, and a fine cutting edge cannot be obtained if .025 of

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[11] Ore Deposits, p. 77.
[12] Iron Ores of North Carolina, p. 23.
[13] Cast Iron, p. 77. 1902.
[14] Manufacture and Properties of Iron and Steel, p. 469, 1904.

one per cent of phosphorus is present. Phosphorus in pig iron while it lessens the strength, yet by its increased fluidity makes a metal suitable for fine and ornamental castings, as it readily follows the shape of the mold and gives a greater soundness to the casting as a whole[15].

In the Basic Bessemer process, the converter is lined with basic material, as calcined limestone or dolomite, which removes the phosphorus from the iron. The same result is accomplished in the Basic Open-Hearth process. According to Wedding[16] (quoted by Nitze) the amount of phosphorus in the pig iron used to the best advantage in these basic processes, should not exceed 3 per cent. Usually pig iron with 2 to 2.5 per cent phosphorus is used; but with as low percentage as 1.2, no results are reached. The pig iron should be low in silica, not over 1.5 per cent, and not over 0.12 per cent sulphur and 2.2 to 3 per cent metallic manganese.

Sulphur. The presence of sulphur renders the iron red-short or hot-short; that is, brittle when hot. Manganese when present tends to neutralize the sulphur. This element has a strong tendency to combine with the slag and so is partially removed in the blast furnace. If sulphur is present in too great quantity in iron ores, it can be removed by washing, before use in the blast furnace.

According to H. H. Campbell,[17] sulphur injures the rolling qualities of steel, causing it to crack and tear, and also lessens its capacity to weld, but all these defects can be overcome to some extent by the use of manganese and greater care in heating. In common steel, 1-10 of one per cent of sulphur apparently does little harm, but in rails it is best to have less than 0.08 per cent. Huntington[18] states that soundness of steel castings and the welding power of steel are both impaired by sulphur.

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[15] Huntington and McMillan, Metals, p. 291.
[16] Iron Ores of North Carolina, p. 24.
[17] *loc. cit.* p. 467.
[18] *loc. cit.* p. 231.

Manganese. This element, when present in iron or steel, tends to neutralize the action of sulphur. It also forms a more fluid slag, causing the iron to be more completely separated from its impurities in the blast furnace.

According to H. H. Campbell,[19] manganese prevents the coarse crystallization which would be caused by impurities if it were absent, and it also raises the critical temperature to which it is safe to heat the steel. At the present time the maximum allowable limit in steel rails is 0.7 to 1.00 per cent, while in structural steel a higher limit may be used.

The effect of large proportions of manganese is peculiar[20]. As the percentage of manganese is increased over 1.5 to 2, the metal becomes brittle and almost worthless, and this remains true with further increase until an alloy is formed with 6 to 7 per cent manganese, when the metal is very hard and becomes tougher when tempered. It thus forms a tough, hard alloy valuable for car wheels, etc., and reaches a maximum toughness when 14 per cent of manganese is present[21], further addition of manganese causes a sudden decrease in ductility, and over 20 per cent brings a rapid decrease in breaking load.

Manganese will replace iron in pig iron to the extent of 85 per cent or more. Pig iron with 5 to 20 per cent of manganese is called *spiegel-eisen,* and with greater percentage is called *ferro-manganese,* both of which are used in the Bessemer process.

Silicon. The element silicon in small quantity appears to have little effect on the ductility or toughness of steel, though some experiments show an increase of 80 pounds to every .01 per cent silicon up to 4 per cent and beyond this a decline. Structural steel usually runs .03 to .05 per cent silicon, while in the best grades of tool steel it runs .20 to .80 per cent.

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[19] *loc. cit,* p. 463.
[20] Campbell, *loc. cit.* p. 467.
[21] Huntington, *loc. cit.* p. 293.

According to other authorities[22], silicon makes the metal both hot and cold short, but its effect depends on the relative proportion of carbon. With carbon reaching 0.10 per cent, silicon might be 0.5 or more and not cause the metal to be brittle, while if the carbon was 0.5 per cent, the same amount of silicon would cause the metal to be hot and cold short.

Acording to Keep,[23] silicon will alloy with iron up to 10 per cent and by special treatment up to 20 and 30 per cent; and by varying the percentage of silicon in white iron, the softness and grayness can be changed at will. He finds the action of silicon is indirect acting through the carbon which the iron contains. Silicon lowers the saturation point of carbon, or the addition of silicon to iron containing combined carbon expels the carbon in graphitic form which is caught between the grains of the iron, giving it a grayer color.

The more total carbon or the less combined carbon in the iron, the less the amount of silicon required to produce a given effect. The influence of silicon upon the physical qualities of a casting is important, and by changing the percentage of silicon in an iron mixture, the condition of the carbon can be controlled. Keep[24] gives the following requirements of different grades of iron which by proper mixture give any desired percentage of silicon in the casting:

White iron contains less than 1 per cent silicon
No. 3 Foundry should contain about 1.50 per cent silicon.
No. 2 Foundry should contain about 2.25 per cent silicon
No. 1 Foundry should contain about 2.50 per cent silicon
No. 2 Foundry should contain about 3.00 per cent silicon
No. 1 Soft should contain about 3.25 per cent silicon
Silvery iron should contain about 4 to 6 per cent silicon
High priced silicon iron contains 6 to 10 per cent silicon

Carbon. Carbon in iron up to a certain point increases tenacity and decreases ductility. It also causes the metal when heated and suddenly cooled to harden, the amount of hardening being directly proportional to the amount of carbon present and the rate of cooling[25]. 1.5 per cent carbon

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[22] Huntington and MacMillan, *loc. cit.* p. 288.
[23] Cast Iron, p. 34.
[24] Cast Iron, p. 41.
[25] Huntington and MacMillan, Metals, p. 278.

is about the maximum for safe work. Steel with 1 per cent carbon can be readily welded. Steel with 0.8 to 0.9 per cent carbon is very useful for high resistance to shock and ability to take a keen cutting edge.

Iron has strong affinity for carbon and when united at high temperature, forms steel. According to Keep,[26] without carbon iron could not be melted readily and made into castings. The percentage of total carbon determines the melting point of iron; and without carbon, the degree of hardness and strength needed for various uses could not be given. The carbon is absorbed by the ore in the blast furnace and the iron contains as much carbon as it could possibly absorb under the conditions existing in the furnace. It usually varies from 2 to 4.25 per cent. The largest quantity of carbon that can be absorbed by charcoal iron is 4 per cent, while for coke iron it does not exceed 3.5 to 3.75 per cent (Keep).[27] In iron with 3 per cent carbon, this element forms about 12 per cent of the entire bulk and in pig iron 4 per cent carbon will form 15 per cent of bulk of the metal. Carbon increases hardness, fusibility, and fluidity and tends to render the iron crystalline thereby reducing shrinkage.

Aluminum. The presence of aluminum in iron appears to increase its tensile strength. According to Campbell, 1 per cent of this element increases tensile strength 3,000 to 8,000 pounds per square inch, and decreases ductility. Keep[28] showed that aluminum alone will make solid gray castings out of porous white iron and he also proved that the aluminum added remained in the casting.

Aluminum added in small quantity to melted steel, on account of its affinity for oxygen, acts as a deoxidizing agent and removes carbonic dioxide and increases the solvent power of the fluid metal for gases, thus preventing their evolution at the moment of solidification.[29]

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26 Cast Iron, p. 25.
27 Keep, Cast Iron, p. 29.
28 *loc. cit.* p. 210.
29 Huntington and MacMillan, Metals, p. 297.

MECHANICAL IMPURITIES.

In addition to the chemical impurities in iron ores, considered above, there are often present minerals mechanically mixed with ores. Among the common mechanical impurities are quartz, sand, carbonate of lime, and clay. Quartz or sand, and clay increase the infusibility of the ore and so require greater amounts of fuel and fluxing material, increasing the cost of manufacture. Carbonate of lime present in the ores aids in their fusion and so may be an advantage.

All of these impurities lower the percentage of metallic iron in a given quantity of ore and therefore increase cost of working as a greater amount of material will have to be handled and treated to secure the same results as in a better grade of ore, and more flux and fuel will be consumed.

If a large quantity of loose clay and sand is present in the ores, it becomes necessary to crush and wash them, which involves additional cost of equipment and working. If the proportion of these materials is very large, the economic value of the ore is very doubtful. Nitze places the maximum percentage of silica in a commercial iron ore at about 30 per cent, and suggests that an ore carrying over this amount would hardly be called an iron ore.

PROPERTIES OF IRON AND STEEL.

Iron and steel possess certain physical properties which determine their value in the arts and trades. A number of these are herein defined.

Malleability, is the property by which a metal can be hammered or rolled into thin sheets without fracture. It depends both on the softness of the metal or the ability of the particles to move one on the other, and also on the tenacity or cohesion of the particles. Iron is malleable, but possesses this property in much smaller degree than many other metals, as shown by the following table arranged in order of decreasing malleability:[30]

[30] Huntington and MacMillan, Metals, p. 166.

1 Gold	4 Tin	7 Zinc
2 Silver	5 Platinum	8 Iron
3 Copper	6 Lead	9 Nickel

Ductility, is the property by which a metal can be drawn out into wire. It depends especially on tenacity or cohesion of the particles. Gold and silver are the most ductile of the metals, as shown in the following table, which shows a different order from the above table of malleability.[31]

1 Gold	5 Nickel	9 Zinc
2 Silver	6 Copper	10 Tin
3 Platinum	7 Palladium	11 Lead
4 Iron	8 Aluminum	

Toughness is the quality of resistance to breaking under the various stresses applied.

Brittleness is the tendency of a substance to fall into particles or powder when hammered or cut. Metals which are brittle and cannot be worked when cold are known as cold-short. Those which are brittle when hot are known as red or hot-short. These qualities are due to presence of certain impurities as already described.

Tensile Strength is the resistance to breaking of a metal bar or wire when stretched, usually stated in pounds per square inch. The tensile strength of pure iron is about 38,000 to 39,000 pounds per square inch; for structural steel 60,000 to 70,000 pounds; and for wrought iron, 48,000 to 50,000 pounds.[32]

Elasticity is the resistance to change in shape or volume, and tendency to return to the original form when the disturbing force is removed. When the metal is stretched to its *limit of elasticity,* it does not return again, but a permanent set results.

Specific Gravity. The density of a body is measured by its specific gravity, which represents the weight of a sub-

[31] Metals, p. 117.
[32] Campbell *loc. cit.* pp. 526, 555, 579.

stance compared with an equal volume of distilled water. It is a useful property in comparing relative weights of bodies. The volume of a solid may be determined by weighing it in the air and then in water, the difference in weights being the weight of the *volume* of water displaced which volume is equal to that of the solid. The weight of the substance divided by its volume is its *specific gravity.*

The following table shows the specific gravity of the different iron ores (Dana Mineralogy):

Magnetite	5.17 to 5.18
Hematite	4.9 to 5.3
Limonite	3.6 to 4.0
Siderite	3.83 to 3.88
Pyrites	4.95 to 5.1
Metallic iron	7.86

The following table affords a comparison between specific gravity of metallic iron and a few other metals and shows that iron is not the heaviest of the metals, but ranges low in the list:

Platinum	21.50	Nickel	8.90
Gold	19.32	Copper	8.82
Mercury	13.59	Iron	7.86
Lead	11.37	Tin	7.29
Silver	10.53	Zinc	7.15

Hardness of a substance is its resistance to abrasion or scratching by another substance. It is usually expressed by numbers corresponding to a group of minerals arranged by Mohs to form a scale of hardness as shown below. A mineral scratched by number 3 and not by 2 would have a hardness between 2 and 3.

1	Talc	6	Orthoclase
2	Gypsum	7	Quartz
3	Calcite	8	Topaz
4	Fluorite	9	Sapphire
5	Apatite	10	Diamond

The iron ores, according to this scale, have the following hardness (Dana):

Magnetite	5.5 to 6.5
Hematite	5.5 to 6.5
Limonite	5. to 5.5
Siderite	3.5 to 4
Pyrites	6 to 6.5

Fracture refers to the form of surface produced on breaking a substance, and shows the following varieties:

Crystalline, when made up of visible crystals.

Conchoidal or shelly, when substance breaks with smooth curved surface, glassy in appearance.

Granular, when fine grained and no distinct crystals visible,

Even when surface is nearly smooth but roughened by slight elevation.

Uneven when surface is rough and irregular.

Hackly when surface is broken into rough and jagged projections.

Splintery or fibrous when surface is broken into slender thread-like projections.

Earthy when surface is powdery or in small loose grains.

Fusibility is the change from a solid state to a liquid condition. Every mineral in a pure state and under uniform conditions has a definite fusion temperature. The temperature of fusion of a number of metals is shown in the following table:[33]

	Cent	Fahr.		Cent.	Fahr.
Tin	232°	449.6°	Gold	1045°	1913°
Lead	327°	620.6°	Copper	1050°	1922°
Zinc	417°	782.6°	Nickel	1450°	2642°
Aluminum	625°	1157.0°	Iron	1600°	2912°
Silver	950°	1742.0°	Platinum	1775°	3227°

Heat Conduction. Metals are better conductors of heat than non-metallic substances. The particles more or less rapidly transmit the heat from one part to another. The order of metals in their conducting power is given in the following table where silver as the best conductor is given a value of 1,000.[34]

33 Metals, p. 120.
34 Metals, page 119.

Silver	1,000	Tin	152
Copper	736	Iron	119
Gold	532	Lead	85
Magnesium	343	Platinum	84
Aluminum	313	Antimony	40
Zinc	281	Mercury	13

Electricity Conduction. According to Huntington,[35] the conducting power for electricity of metals, refers to the facility with which an electric disturbance excited in one portion of a mass of metal is transmitted to the other particles composing the mass. He gives the following table showing the relative electricity conducting power of metals in a pure state at freezing point, the best conductor silver being taken as 1,000:

Silver	1,000	Platinum	167
Copper	999	Iron	164
Gold	806	Tin	152
Aluminum	551	Lead	88
Zinc	302	Nickel	79

Welding[36] is the operation by which wrought iron, and the milder varieties of steel, may be firmly joined by placing clean ends together and hammering or pressing while the pieces are at the proper temperature. Wrought iron is at the correct temperature when in a plastic condition.

NOMENCLATURE OF IRON AND STEEL.

Wrought Iron[37] is an iron manufactured without complete fusion. It consists of fibers of the metal interspersed with more or less slag which prevents crystallization. It contains chemical and mechanical impurities, and is often called malleable iron.

Ingot Iron is manufactured with fusion and is practically free from slag. It is sometimes called mild or machinery steel, but cannot take a temper.

Cast Iron is an iron containing all the carbon that it could absorb during its reduction in the blast furnace. It

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35 Metals, p. 119.

36 MacFarlane, Iron and Steel Manufacture, p. 10.

37 Keep, Cast Iron, p. 3.

cannot be welded, forged, or take temper. White cast iron fuses at about 2075° F., and the gray at 2230° F.

According to Keep, cast iron is not a simple metal nor an alloy, but it is an aggregate of compounds combined chemically and mechanically. It really includes any iron with carbon too high for steel, and is separated into many grades. These grades are often separated by differences in appearance of exterior surface or by the fracture, though at present time more attention is given to the chemical composition than to physical appearance.

Gray pig or gray cast iron on fracture has the iron nearly or quite concealed by graphite, so that the fracture has the gray color of graphite, while white pig iron or white cast iron shows on fracture little or no graphite so the fracture is silvery or white (Stoughton).

Steel is a difficult term to define, as it grades into ingot and cast iron. It is sometimes defined as an iron with small percentage of carbon, which will take a temper. H. H. Campbell[38] states in his treatise on this subject that no perfectly satisfactory definition can be given, but suggests that the term steel applies to the product of the cementation process (the penetration of the metal by carbon), or the malleable compounds of iron made in the crucible, the converter, or the open-hearth furnace.

Stoughton in his recent book (Metallurgy of Iron and Steel, 1908) states that the word steel is used in so many ways by manufacturers that it is difficult to give a good definition, and suggests the following:

Steel is an iron which is malleable at least in some one range of temperature, and in addition is either,

(a) cast into an initially malleable mass, or

(b) is capable of hardening greatly by sudden cooling, or

(c) is both so cast and so capable of hardening.

Cast Steel properly refers to a very high grade steel made of purest iron by most careful methods in small crucibles, and is used for tools and cutlery. The noted locality for this

[38] *loc. cit.* pp. 140, 146.

work is Sheffield in England. In this country the term cast steel is sometimes applied to a specially prepared steel, cast for car springs. It is made in open-hearth furnace.

CHEMICAL ANALYSES OF IRON ORES.

It is often a matter of interest as well as of importance to compare the ores of a state with those mined in other districts, especially is this true in a state where the ores occur in quantity but are not as yet developed. For the purpose of comparison a number of iron ore analyses from important districts are given below.

Magnetite Analyses.

	Cornwall, Pa.[39]	North Carolina.[40]	Alabama.[41]	New York.[42]	Sweden.[43]
Metallic iron	64.90	63.71	47.83	57.42	56.91
Silica	3.98	11.69	13.00	8.32	.....
Alumina	0.324	.....	6.98	3.45	.....
Lime	1.010	0.16	.....	4.46	.....
Magnesia	1.131	0.17	.....	3.09	.....
Phosphorus	0.014	0.003	0.147	0.14	0.009
Manganese	0.158	.....	.....	0.23	1.31
Sulphur	0.071	0.006	.....	0.35	0.036
Copper	0.005				

Analyses of Lake Superior, Hematite Ores.[44]

	Gogebic. Ashland Mine	Marquette. Salisbury Mine	Menominee. Florence Mine	Mesabi. Biwabik Mine	Vermilion. Savoy Mine
Metallic iron ...	53.40	52.06	49.43	56.42	60.71
Silica	6.54	6.62	5.78	3.40	3.89
Alumina	2.75	2.00	3.21	1.60	.....
Lime	0.222	0.50	1.27	0.45	.....
Magnesia	0.231	0.44	2.37	0.24	.....
Sulphur	0.008	0.010	0.116	0.007	.....
Manganese	0.240	0.516	0.20	0.417	0.93
Phosphorus	0.040	0.110	0.279	0.040	0.041
Loss by ignition	2.45	2.07	4.24	3.90	.....
Moisture	11.00	12.50	10.46	9.34	5.71

39 McCreath, Geol. Survey of Pa. Annual Report 1885, p. 532.
40 Nitze, Iron Ores, North Carolina, p. 77.
41 Winchell Iron Ores of Minn. Bull. VI, p. 90.
42 Blake quoted Iron Ores of Minn. Bull. VI, p. 88.
43 Blake quoted Iron Ores of Minn. Bull. VI, p. 92.
44 Avg. Cargo Analyses Lake Superior Iron Ore Association 1906, quoted by Eckel, U. S. G. S. Mineral Resources, 1906.

The following analyses are taken from the Cargo Analyses for 1900 of same mines shown in the above table for 1906. A comparison of the two tables shows a decline in percentage of metallic iron for three of the mines. Eckel, in report quoted above, figures the average decline of the Lake Superior ores for past five years as about 1 per cent a year in iron content.

	Gogebic.	Marquette.	Menominee.	Mesabi.	Vermilion.
Metallic iron	54.636	52.17	49.20	59.47	59.30
Silica	.....	6.303	5.80	2.22	3.21
Alumina	.....	2.139	3.41	0.842	.....
Lime	.....	0.355	1.36	0.157	.....
Magnesia	.....	0.407	2.67	0.083	.....
Sulphur	.....	0.0095	0.114	.....	.....
Manganese	.....	0.2286	0.36	0.592	.....
Phosphorus	0.039	0.094	0.281	0.034	0.048
Loss by ignition ...	.....	2.269	4.93	3.496	.....
Moisture	11.03	13.05	9.93	7.51	6.71

Analyses of Clinton Fossil Hematite Ores.

	Lowmoor, Va.[45]	Birmingham, Ala.[46] hard ore.	soft ore.	Kentucky[47].	Penna.[49] Mifflin Co.
Metallic iron ...	57.00	54.70	37.00	36.00	50.10
Silica	7.12	13.70	7.14	7.80	16.95
Alumina	6.31	5.66	3.81	5.132	4.49
Lime	1.46	0.50	19.20	13.080 (carb)	0.56
Magnesia	0.08	.....	.....	9.444 (carb)	0.342
Phosphorus	0.672	0.10	0.30	0.497	0.268
Manganese	0.15	0.23	0.23	.....	0.475
Carbon dioxide .	1.23	.....	.....	.....	.....
Sulphur	....	0.08	0.08	.....	0.014
Water	1.18	.....	.....	.....	4.753

[45] Eckel. U. S. G. Bull. 285, p. 188.
[46] Eckel. U. S. G. Bull. 315, p. 135.
[47] Kindle. U. S. G. Bull. 285, p. 181.
[48] McCreath. Penn. Geol. Sur. Report M. 3, p. 39.

Analyses of Limonites.

	Alabama[49].	Covington, Va.[50]	New Riv. Va.[51]	North Carolina.[52]	Ohio.[53]	Pennsylvania.[54] Center Co.
Metallic iron	58.459	36.96	43.76	49.29	39.2	57.10
Silica	2.864	33.26	13.52	7.63	13.61	4.53
Alumina	1.411	5.26	1.79	.....	3.00	1.49
Lime	0.407	0.28	.....	.....	2.90	trace
Magnesia	0.045	.....	.....	.....	1.95	0.47
Phosphorus	0.332	0.573	0.17	0.663	0.014	0.07
Manganese	0.188	0.61	0.58	0.060	.....	0.10
Sulphur	0.085	0.014	.....	.....	0.34	.....
Combined water..	11.849	.....	.....	.....	.....	.....
Moisture	0.833	1.90	.....	.....	.....	11.70

Analyses of Siderite Iron Ores.

	Blackband ores, Ohio.[55]		Perry County, Pa.[56]
Iron carbonate	45.86	43.26	.....
Iron sesquioxide	7.40	8.94	.....
Silica	25.52	11.84	13.27
Alumina	0.50	trace	3.475
Lime carbonate	1.50	1.87	0.510 (oxide)
Magnesium carbonate	3.26	2.03	0.335 (oxide)
Manganese	2.10	1.00	0.490
Phosphorus	0.043	.....	0.189
Sulphur	0.17	0.18	0.042
Volatile and combust. matter	13.30	30.50	13.740
Metallic iron	27.32	27.12	47.25
Iron in calcined ore.......	43.94	.....	.....

[49] McCalley quoted U. S. G. S. Bull. 315, p. 154.
[50] Eckel, U. S. G. S. Bull. 285. p. 187.
[51] Holden, U. S. G. S. Bull. 285, p. 191.
[52] Nitze, Iron Ores of North Carolina, p. 115.
[53] Lord, Ohio Geol. Survey, Vol. V, p. 496.
[54] McCreath. Geol. Survey of Pa. Summary Final Report, Vol. I, p. 384.
[55] Ohio Geol. Survey. Vol. V., pp. 401, 460.
[56] McCreath Geol. Survey of Pa. Report M. 3, p. 31.

IRON ORE INDUSTRY OF THE UNITED STATES.

Mr. Edwin C. Eckel has recently given a concise and interesting account of the present iron industry in the United States in a report for Mineral Resources division of the U. S. Geological Survey for 1907, and a portion of his article is incorporated in this chapter to show the present centers of the industry and their relative importance. Full credit should be given Mr. Eckel and the U. S. Geological Survey for the statements which follow:

Iron ore is mined for blast furnace use in 26 states which may be grouped in four natural districts:

1. Lake Superior District, including Michigan, Minnesota and Wisconsin.

2. Southern District, including Alabama, Georgia, North Carolina, Tennessee, the Virginias, Maryland, Kentucky, Arkansas, Missouri and Texas.

3. Northern District, including New England, New York, New Jersey, Pennsylvania, Ohio and Iowa.

4. Western District, including Colorado, Utah, Wyoming, California, Washington, New Mexico, Nevada and Montana.

The following table compiled by Eckel shows the present relative importance of these districts in 1905, 1906 and 1907:

	1905		1906		1907	
	Quantity, long tons.	Percentage of total.	Quantity, long tons.	Percentage of total.	Quantity, long tons.	Percentage of total.
Lake Superior	33,480,367	78.73	38,035,084	79.66	41,638,744	80.51
Southern	5,700,819	13.41	6,325,710	13.24	6,427,195	12.42
Northern	2,520,845	5.93	2,582,666	5.41	2,823,422	5.46
Western	824,102	1.93	806,268	1.69	831,258	1.61
Total	42,526,133	100.00	47,749,728	100.00	51,720,619	100.00

Lake Superior District.

The Lake Superior District in 1907 produced 80 per cent of the total American output and is the most important iron district in the world. The Mesabi range produced over 3-5 of the entire Lake Superior output in 1907. The entire district shipped 41,288,755 tons by water, and the balance, less than a million tons, by rail. 35,195,758 tons of the Lake shipments reached Lake Erie ports. The price per long ton in 1907 for Bessemer ores was $4.75 to $5.00 and for non-Bessemer ores $4.00 to $4.20, an increase, figured according to iron content, of 92 cents a ton for Bessemer ore, and 63 cents a ton for non-Bessemer. The ores are practically all hematites.

Southern District.

The Southern District ores are nearly all non-Bessemer, and of two types: (1) red hematite with iron content 35 to 40 per cent, but frequently with enough lime to be self-fluxing; brown hematite (limonite) with 38 to 52 per cent iron, usually high in silica. The ores, while not adapted to Bessemer steel work, are used for steel manufacture by the open-hearth process.

In Alabama there are six ore districts, of which the Birmingham is the most prominent in red hematite, and Russellville in brown hematite. In Georgia the present production is in a small area in the northwestern corner of the state where the Clinton fossil red hematite and the Cambro-Silurian limonites are worked. In Maryland the iron ores have come from the Coastal Plain area where limonites are associated with Cretaceous sands and clays, and also the Cambro-Silurian limonites in the Valley region. The present large Maryland pig iron production is not based on local ores but on ores imported from Cuba and Spain. In North and South Carolina there are important deposits of known hematites and magnetites, but at present time only worked at Cranberry mines in North Carolina.

In Tennessee red and brown hematites are worked, and afford important future sources of supply. Very little iron is produced in Texas, Arkansas and Missouri. The most promising field for future work is in the northeastern counties of Texas, where beds of brown hematite and magnetite are found. In Virginia occur large deposits of brown and red hematites and magnetites. At present the important ores are the Oriskany limonites or brown hematites of the Goshen-Longdale-Oriskany district. In West Virginia there is only one producing mine, located near Harpers Ferry, but the brown hematite will prove a valuable future source of supply.

Northern District.

The Northern District produces a little less than 5½ per cent of total American output, but according to Eckel, its reserves of ore will compare favorably both in quantity and quality with those of Lake Superior district. In New England the important ores are in Vermont, western Massachusetts and northwestern Connecticut where Cambro-Silurian brown hematites are found. In New Jersey the most important iron ores are the magnetites in the highland portion of the state.

In New York, while brown hematites and fossil red hematites are found, the important ores are the magnetites of the Hudson highlands and the Adirondacks, and the red hematites of the western Adirondacks. In Ohio the only iron ores now mined are the carbonates associated with the coal rocks of the eastern and southeastern portions of the state, and these are worked on a small scale. The present supply of ore in Pennsylvania comes from the brown hematites and magnetites in southeastern portion of the state. The Clinton fossil red hematites were formerly worked, and may become important in future.

Western District.

The western district, including the Rocky Mountain and Pacific Coast states, produces less than 2 per cent of total. There is only one furnace company operating, namely, the Colorado Fuel and Iron Company.

Statistics.

The following table from Eckel's report of U. S. Geological Survey shows the production of iron ore in long tons (2,240 pounds) in the different states for 1907.

IRON ORE PRODUCTION OF UNITED STATES FOR 1907 (Eckel).
(Long tons.)

Rank.	State.	Brown hematite.	Red hematite	Magnetite.	Carbonate.	Total quantity.	Total value.
3	Alabama	895,442	3,144,011	....	......	4,039,453	$ 4,863,129
12	Arkansas & Texas	118,667	....	....	......	118,667	120,060
18	Colorado	11,714	....	....	......	11,714	21,085
16	Conn. and Mass.	37,166	....	....	......	37,166	136,440
11	Georgia	337,229	106,885	....	......	444,114	837,102
14	Ky. Md. & W. Va.	26,808	36,000	....	......	62,808	95,891
2	Michigan	....	11,830,342	....	......	11,830,342	36,441,330
1	Minnesota	....	28,969,658	....	......	28,969,658	76,668,836
13	Missouri	69,241	42,527	....	......	111,768	226,286
7	Montana, Nevada, New Mexico, Utah & Wyoming	16,000	608,056	195,488	......	819,544	967,190
10	New Jersey	46,818	....	502,942	......	549,760	1,815,586
4	New York	10,000	140,101	1,224,919	......	1,375,020	
15	North Carolina .	....	....	50,439	......	50,439	113,488
17	Ohio	....	....	....	23,589	23,589	41,081
6	Pennsylvania . .	113,076	19,403	704,808	......	837,287	1,298,717
8	Tennessee	544,508	269,182	....	......	813,690	1,325,134
9	Virginia	696,518	89,867	471	......	786,856	1,538,920
5	Wisconsin	34,290	804,454	....	......	838,744	2,665,737
	Total	2,957,477	46,060,486	2,679,067	23,589	51,720,619	$131,996,147

In 1907 over 1,200,000 long tons of iron ore were imported. Over one-half of this quantity came from Cuba and one-third from Spain.

Iron Ore Industry of the World.

Mr. Eckel, in the United States Geological Survey report on Mineral Resources for 1907, gives the following list of countries in the world producing iron ore and the quantity. The figures for United States, Great Britain, Cuba, Canada and Australia are in long tons (2,240 pounds), while those for the other countries are in metric tons (2,205 pounds).

World's Production of Iron Ore in 1905 and 1906 (Eckel).

Country.	1905.	1906.
	Tons.	Tons.
United States	42,526,133	47,749,728
Germany and Luxemburg	23,444,073	26,734,000
Great Britain	14,590,703	15,500,406
Spain	9,077,245	9,448,533
France	7,395,400	8,481,000
Russia	6,050,000	....
Sweden	4,365,967	4,503,000
Austria-Hungary	3,697,679	4,088,466
Canada, Newfoundland	963,543	951,752
Cuba	561,159	640,574
Algeria	568,609	780,000
Greece	465,622	680,620
Italy	366,616	405,000
Belgium	176,620	177,000
China	123,000	111,460
India	102,120	74,106
Japan	100,000	....
Norway	46,582	109,259
Australia	11,184	34,001
Portugal	3,200	....

CHAPTER II.

FUELS AND FLUXES.

While heat may be generated in a variety of ways, friction, electricity, chemical combination, etc., the important method for most metallurgical processes is by chemical combination.

Fuel for the production of heat in a practical way, is composed of or derived from organic matter, especially vegetable, more or less consolidated and is composed essentially of the elements, carbon, hydrogen, oxygen and nitrogen. When the element carbon unites with oxygen, heat is evolved which reaches a maximum when one atom of carbon unites with two of oxygen, forming the compound $C\,O_2$ or carbonic acid. When one pound of carbon unites with enough oxygen to form carbonic acid gas (CO_2), sufficient heat is generated to raise 8,080 pounds of water, 1° centigrade, while if only enough oxygen unites to form carbonic monoxide (CO) the heat generated will raise only 2,400 pounds of water 1° C.

In practical work, the fuel is burned in air which contains in addition to oxygen, over three-fourths nitrogen. It becomes necessary to use an excess of air to insure complete combination of the carbon of the fuel. According to H. H. Campbell,[1] it is seldom possible to have complete combination or combustion of the fuel with less than 30 per cent excess of air. He gives the following table, showing the products of combustion of hard and soft coal with different amounts of air. The first line of the table with no excess of air represents the results with just sufficient air to completely oxydize or burn the oxygen and hydrogen. Soft coal shows lower results on account of the presence of moisture which must be vaporized with a loss of available heat. In the table

[1] Manufacture and Properties of Iron and Steel, p. 234.

the lower the percentage of CO_2 evolved, the poorer the combustion and the greater the waste of available heat in the coal.

PRODUCTS OF COMBUSTION OF HARD AND SOFT COAL.

Excess air, *Per cent.*	Hard Coal.		Soft Coal.	
	CO_2 *Per cent.*	Oxygen. *Per cent.*	CO_2 *Per cent.*	Oxygen. *Per cent.*
No excess	21.0	0.0	19.1	0.0
10	19.1	1.9	17.3	2.0
20	17.5	3.5	15.8	3.6
30	16.1	4.8	14.5	4.9
40	15.0	6.0	13.5	6.1
50	14.0	6.9	12.6	7.1
60	13.0	7.8	11.7	8.0
70	12.3	8.6	11.0	8.8
80	11.7	9.3	10.4	9.5
90	11.1	9.9	9.9	10.1
100	10.5	10.5	9.4	10.6

In addition to loss of heat by excess of air and incomplete combustion, much available heat of the fuel is wasted in the heat of escaping gases. Campbell has computed that by gases escaping with temperature of 200°C (392°F) from a coal fired boiler, the loss in heat would be 7.5 per cent if no excess of air is admitted; but with 100 per cent excess of air the loss would be 14.4 per cent; or escaping with temperature 400°C (752°F) and same amount of excess air, the loss would be 29.5 per cent. The theoretical heating value of a fuel is never secured in use, and attempts are constantly made to lower the loss.

The heating value of a fuel is expressed conveniently in terms of Calories or British Thermal Units, and in this country the latter term is more commonly used. The British Thermal Unit (B. T. U.) represents the number of pounds of water one pound of fuel will raise one degree Fahrenheit, or using the metric system, the calorie represents the number of kilograms of water one kilogram of fuel will raise one

degree Centigrade. The heating value of coals expressed in calories can be changed to British Thermal Units by multiplying the number of calories by nine-fifths.

For illustration, the Pittsburg coal at Fairmont has a heating value of about 14,200 B. T. U. and is regarded as a very high grade of soft coal. The highest calorific or heating value found in the coals of this state is 15,927 B. T. U., in the Pocahontas coal.

The heating or calorific power of a substance during its combustion will be the same in amount whether combustion takes place slowly or rapidly. The calorific intensity will be greater when burned rapidly, and will depend on the state of aggregation, freedom from moisture, also on its composition and on the nature of the atmosphere in which it is burned, and on the nature of the ultimate products of combustion.[2] The fuel for generation of high temperatures should be high in carbon and free from moisture. The following fuels are important in the working of the non-metallic and metallic products: wood, charcoal, coal, coke, gas, oil.

WOOD.

Wood is composed of carbon, hydrogen, oxygen, nitrogen, with an average composition when dried, as follows:[3]

Carbon	49.3 per cent
Hydrogen	6.3 per cent
Oxygen	43.3 per cent
Nitrogen	1.1 per cent

or expressed in a different way, and compared with soft coal, charcoal and coke.[4]

	Wood.	Coal.	Charcoal.	Coke.
Fixed Carbon	25	56	92	87
Hydrocarbons, etc.	52	33	1	2
Ash	1	5	4	8
Water	22	6	3	3

[2] Huntington and McMillan, Metals, p. 3.
[3] Metals, p. 15.
[4] MacFarlane, Iron and Steel Manufacture, p. 226.

Wood is not adapted to production of high temperatures, according to Huntington, since its calorific power is only 3,600 calories, and after air drying, still contains 18 to 20 per cent water. If this water is removed at 100°C., it will be reabsorbed when the dried wood is exposed to the air. The temperature of combustion of average wood in presence of air is about 300°C. (572°F.).

CHARCOAL.

When wood is burned with as little air as possible, carbon dioxide, water, oils, tar, etc., escape and the residue consists mostly of carbon with a little hydrogen and oxygen. The process of distillation begins at about 150°C (302°F) and is practically completed at 360 to 400°C. (680 to 652°F.), and the product is called charcoal.[5]

Good charcoal preserves the form of the wood from which it is made. Its density depends partly on that of the wood, and also on the method of burning. Rapid burning makes the charcoal light and friable, while slow combustion makes a compact and dense product. When properly burned, charcoal is perfectly black, hard, and does not soil the hands.

The yield of charcoal by weight varies with wood used, its condition when used, and method of burning. The weight varies, according to Huntington, between 15 and 28 per cent of the weight of the wood used. The slower the process the greater will be the yield. The yield by volume is 50 to 75 per cent and the weight of ash is usually 2.5 to 3 per cent.

In the days of the old charcoal iron furnaces, a vast amount of timber was consumed. The following statement by N. W. Lord,[6] with reference to the old furnaces in Ohio, illustrates the large amount of timber required for their use.

The Pine Grove Ohio hot-blast furnace in 1869, produced 3,102 tons (of 2,268 pounds) of iron and consumed 11,045 cords of wood which yielded 36.8 bushels of charcoal per cord.

[5] The section on charcoal is based on the discussion by Huntington and McMillan, Metals, pp. 16-23.
[6] Ohio Geol. Survey, Vol. V., p. 493.

or a total of 406,456 bushels. This would be 131 bushels of charcoal, or 3.56 cords of wood per ton of iron. The Hecla Ohio cold-blast furnace consumed 201 bushels of charcoal per ton of iron. Stated in another way, a furnace will consume the wood from 250 acres of land per year, to provide for regrowth and ensure a perpetual supply of timber, such a furnace would require 800 to 1,000 acres of wooded land. A wagon load of charcoal contains 200 bushels, and was made and delivered at the Ohio furnaces in 1870-1 at a cost of 8 1-10 cents a bushel.

Mr. Jack Thorp, an old charcoal burner at the Capon furnace, of Hardy county, gives the following description of their method of burning or coaling.

A piece of ground was made level for about 90 feet across and sufficient size to hold 30 cords of wood. The lap wood was first placed around the level area and the cord wood piled on the space against it. A chimney was made in three-corner shape, out of cord wood, laid horizontal. The second tier of cord wood laid around it and covered with leaves so as to make the pile air-tight and prevent dirt from coming in. The whole pile was then covered with dirt, two or three inches thick at bottom and seven or eight inches on the top.

In firing, small pieces of wood were placed in the chimney flue, and a bed of hot coals thrown in on this wood. After fire was well started the chimney was filled with wood and the rapidity of burning controlled by a cover over the top of the chimney. When all the wood was burned out in the flue more was thrown in. Around the bottom of the coal heap, pipe holes were made and opened and closed so as to draw the fire to different parts of the mass.

It required six days of burning before any coal could be drawn. If carefully burned the yield should be 40 bushels of charcoal to the cord of wood.

A pit holding more than 40 cords of wood, in Mr. Thorp's experience, would not give as good results in drawing; 400 bushels of coal could be removed at a time, using great care that it did not take too much air and thus catch fire.

COKE.

In nearly all modern blast furnaces, coke is used as fuel. When coal is heated with a limited supply of air, it is converted into coke. The water, and volatile combustible matter are mostly removed, giving a fuel with carbon in a more or less concentrated form which is capable of generating a very high temperature.

Good coke must have strength to support the burden of ore in the furnace. It has a brilliant silver luster, and is porous or cellular. It should be low in phosphorus and sulphur. Coke is composed essentially of carbon and ash with not over 2 to 2½ per cent of volatile matter. Some cokes contain 18 to 20 per cent of ash, but a good coke should not have over 10 to 12 per cent. Coals which make a coke high in ash could be washed before coking. The following analyses show the composition of a number of cokes used in iron manufacture:

Locality.	Water.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Specific Gravity.
Mingo Junction, Ohio[7]	0.40	1.30	91.28	7.38	1.97	.....	....
Leetonia, Ohio[7]	....	....	89.30	8.04	2.66	.....	....
Avg. 3, analyses, Connellsville[7]	....	....	88.08	10.88	1.03	.....	....
Connellsville, Pa.[7]	0.49	....	87.45	11.33	0.69	.....	....
Avg. 3, analyses, Connellsville[8]	0.79	1.31	86.38	11.54	0.69	0.005	1.80
Monongah, W. Va.[8]	0.23	0.80	89.77	9.80	0.97	0.029	1.82
Pocahontas, Va.[8]	0.34	0.34	92.69	5.88	0.738	0.006	1.83

Fulton gives the following table of physical properties of coke:

[7] Newton in Ohio Geol. Survey, Vol. V., p. 559.
[8] Fulton, "Coke."

Locality.	Grams in 1 cubic inch.		Pounds in 1 cubic foot.		Percentage by volume		Compressive strength. Pounds per cubic inch, ¼ ultimate strength.	Height (feet) furnace charge supported without crushing.	Hardness, per cent.	Specific Gravity.
	Dry.	Wet.	Dry.	Wet.	Coke.	Cells.				
Connellsville Coke	12.51	21.62	47.69	82.20	43.93	56.07	290	115	3.0	1.80
Monongah, W. Va.	12.63	22.05	48.11	84.02	42.33	57.67	306	122	3.2	1.82
Pineville, Ky. ...	14.10	22.24	53.73	84.73	50.37	49.63	227	91	2.6	1.71
Pocahontas, Va. .	15.67	23.53	59.68	89.64	52.07	47.93	236	94	2.5	1.83

Method of Coking Coal. Most of the coke in this country is made in bee-hive ovens. This is also true in England, but very few such ovens are used in France and Germany. These ovens, shaped like the old form of bee hives, are somewhat conical in shape, usually 12 feet in interior diameter, and six feet high. They are constructed of number one fire brick with the arch three feet thick and rest on a stone foundation. They are set in double rows or blocks, the ovens on one side backed against those on opposite side with an overhead car track along the center line of the block. The bed of the oven consists of three feet of compact ashes on which rests the fire-brick floor, and the ovens are surrounded by pounded ashes and faced with a stone wall.

At the top of each oven is a circular opening one foot in diameter for filling the oven with coal and for escape of gases during the burning process. An iron plate closes the opening when coking operation is completed. In front and near bottom of the oven is an opening 30 inches square through which the coke is withdrawn and which is closed by brick and clay plaster during the process of burning. Water is piped convenient to each oven for use in quenching the fires when the coke is finished.

The operation of these coking ovens is thus described by Newton.[9]

"A charge having been removed from the oven, the walls are at a very dull red heat, the temperature having been reduced during the cooling and discharge of the coke. The fresh charge is made directly into the charging hole at top from the cars by means of portable chutes. The charge is then leveled in the oven by a long poker; the front door is closed by brick work, and luted, excepting a small space at the top of the door-way, which is left open for the admission of air to consume the gases. At first a dense volume of smoke issues from the openings in the top of the oven, but in a short time the temperature of the oven has risen high enough to ignite the gaseous mater, which then bursts into flame and issues several feet above the top of the oven. The air admitted through the openings in the door-way should be only sufficient to sustain the combustion of the volatile matter, which burns in the vault of the oven above the bed of coal, and not a little skill is required, especially in stormy weather, to so regulate the admission of air that there shall be no excessive burning of the coal.

"As long as the distillation continues, and volatile matter is being expelled from the coal, it will be denoted by the flame at the top of the oven. When the flame ceases the volatile matter has been driven off, and the coking operation proper completed. The front door is now luted up tightly to exclude all air, and an iron plate is placed over the opening in the top, which is covered with ashes to seal it tightly. The oven is then hermetically sealed, and is left to cool for 12 hours, at the expiration of which time brick work is removed from the doorway, and the coke quenched by water, introduced through a long iron pipe. The quenching of the coke requires a few minutes only, when it is ready to be withdrawn. A small iron bar is placed across the doorway and held in place by staple on either side, and upon this the workman rests the handle of the long rake or hoe with which he hauls the coke from the oven. This is an exceedingly

[9] Ohio Geol. Survey, Vol. V., p. 568.

arduous labor, and requires about 20 minutes for the complete cleaning of the oven. If the coke should not be thoroughly extinguished it is wetted again with water, and then shoveled into wagons by pronged forks that leave the fine and useless coke dust. The oven having been cleared, a new charge is then made as already described. The total time of the operation is usually 36 hours, though it is sometimes prolonged to 72 or 76 hours. The increased time is principally added to the time of cooling, and though the coke is made more dense and hard, the advantage is not always repaid by the increased expense. In the Connellsville region the time of coking is 37 to 38 hours, and the common charge of an oven is 100 to 110 bushels of coal, weighing 76 pounds each."

By-Product Ovens. In the use of bee-hive ovens, it is estimated that the loss per ton of coal is 300 pounds of coal, 10 gallons tar, 3½ pounds ammonia, and 4,000 cubic feet of gas. In 1906, 32,000,000 tons of coke were made in bee-hive ovens in the United States, which represent a waste as follows:

Coal........	7,425,000	tons.
Tar.........	495,000,000	gallons.
Ammonia ...	140,000,000	pounds.
Gas.........	198,000,000,000	cubic feet.

The waste in gas is thus greater than the total output of natural gas in West Virginia and Pennsylvania, the two leading states in production.

In order to save at least a portion of these by-products, ovens have been patented and constructed under the name of by-product or retort ovens. The coal is heated in closed retorts by the combustion of the gases, and the excess gas is taken from the tops of the retorts and carried to purifiers where the tar and ammonia are removed, There are two prominent types of retort ovens used in this country, the Semet-Solvay oven with horizontal heating flues, and the Otto-Hoffman with vertical flues.

TheSemet-Solvay ovens used at Benwood, West Virginia, consist of two batteries of 60 retorts each, one battery

with three horizontal flues and the other with four. The retorts are 30 feet long, 16 inches wide, and 5½ and 7 feet high. The Connellsville coal used, yields 70 per cent coke or 500 tons in 24 hours from the two batteries, and is used by the Riverside Steel plant. The composition of the coke and also of the typical Connellsville bee-hive coke are shown in the following two analyses made by the company chemist:

	By-product Coke.	Connellsville Coke.
Volatile Combustible matter..	1.95	1.31
Fixed carbon	87.17	86.88
Ash	10.88	11.54
Sulphur	0.68	0.695
Phosphorus	0.007	0.005

There are two objections urged against retort oven coke in this country, the greater cost of construction of the ovens and the prejudice against its dull appearance, and opinion among many iron and steel operators that it has a low value for furnace use and is not satisfactory for this work. That this objection or prejudice is not true is proven by the successful use of by-product coke in most of the iron furnaces of Germany, and many of those in England, as well as a number of furnaces in this country.

According to H. H. Campbell[10] the advantages of retort coking ovens are very prominent when coal low in volatile matter is used, for when such a coal is coked in bee-hive ovens much fixed carbon must be burned to supply the necessary heat so that the yield of coke is reduced. With a coal rich in volatile matter, the yield of coke is about the same in retort and bee-hive ovens, but there will be an important saving of gas and other products in the retort ovens. Further coals are known to yield an excellent coke in retort ovens which are failures in the bee-hive ovens.

Blauvelt[11] cites an example where an iron furnace was operated by use of Connellsville by-product coke and later by Connellsville bee-hive coke, without any indications in the working of the furnace, that there was any difference in

10 Manufacture and Properties of Iron and Steel, p. 262.

11 Mineral Industry, Vol. IV., also quoted Alabama Geol. Survey, 1898, p. 129.

the fuel. Blauvelt suggests that with more careful comparisons, the hardness of retort coke will probably show a lower fuel consumption and a cooler furnace top, owing to the weaker action of the furnace gases on the harder coke.

Mr. E. W. Parker, in his careful compilation of statistics of coke in 1906 and 1907 for the U. S. Geological Survey, states that the Cambria Steel Company of Johnstown, Pa., has added a fourth installment of 112 ovens to its by-product plant, making a total of 372 ovens, which argues well for the successful use of retort coke at this plant. He also states that the United States Steel Corporation at their new steel plant at Gary, Indiana, will operate 1,000 retort ovens. Mr. Parker concludes from the successful use of this method in the past that "in course of time the wasteful bee-hive oven must give place to the more advanced and more economical recovery oven, and with this change will come a transfer, in large part, of the coking industry from the coal mining region to points nearer the places of consumption, particularly of the coke and gas, and with this will also be made a long stride in the abatement of the smoke nuisance, from which so many of the interior and western cities are endeavoring to escape."

In regard to market demand for the by-products, Mr. Parker states the importations of coal-tar products reached several million dollars, and that the fuel-briquetting industry is now held back by lack of supply of coal-tar pitch. He also shows that long distance transportation of the gas has been proved practicable and that the Otto-Hoffman plant at Camden, New Jersey, is now supplying gas to Plainfield, New Brunswick and other cities, with a maximum distance of 83 miles.

The average yield of coke in the retort ovens of the United States in 1906, according to Mr. Parker, was 73.6 per cent of coal in coke, and 75 per cent in 1907, while in bee-hive ovens the yield was 60 to 65 per cent.[12] The first plant to use by-product ovens was erected in 1893 at Syracuse, New York, with 12 Semet-Solvay ovens with a coke production that year

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12 The statistics which follow are taken from U. S. G. S. reports on coke in Mineral Resources for 1906 and 1907, by E. W. Parker.

of 12,850 tons. The production of by-product coke in the United States in 1906 was 4,558,127 tons, a gain of 31.6 per cent over 1905, the production in 1907 was 5,607,899 tons, an increase of 25 per cent. At the close of 1907 there were 1,295 Semet-Solvay ovens, 2,002 United-Otto type and 50 building, 387 Rothberg ovens and 208 Newton-Chambers ovens, or a total of 3,892 ovens, of which 3,811 were in operation.

The most important coking district in this country is the Appalachian field, which includes Pennsylvania, Virginia, West Virginia, Ohio, Kentucky, Tennessee, Georgia and Alabama. Pennsylvania holds first rank, producing over half the total coke of the United States. West Virginia holds second rank and Alabama third. In 1907 only five states produced over a million tons.

Pennsylvania	26,513,214	tons
West Virginia	4,112,896	"
Alabama	3,021,794	"
Virginia	1,545,280	"
Colorado (Utah)	1,421,579	"

The Connellsville district, upper and lower, in Fayette and Westmoreland counties, produced 77 per cent of the total coke of Pennsylvania and 50 per cent of the total of the United States.

In the United States in 1907, there were 90,935 active bee-hive ovens and 3,811 active by-product ovens, in which 61,846,109 tons of coal were coked, yielding 40,779,564 tons of coke.

West Virginia Coking Industry.[13]

In West Virginia in 1907, there were 19,568 bee-hive ovens, 459 building and 120 by-product ovens, which used 6,536,795 tons of coal, making 4,112,896 tons of coke with a value of $9,717,130 or a value of $2.36 a ton. The average yield of coal in coke for the year was 62.9 per cent.

[13] Statistics from E. W. Parker, *loc. cit.*

E. W. Parker, in report quoted above of U. S. Survey, divides the state into five coking districts: Upper Monongahela and Upper Potomac in the northern part of the state and drained by the headwaters of these rivers; and in the southern part of the state the Kanawha, New River, and Flat Top fields. The Flat Top field produces over 50 per cent of the coke of the state, and ranks next to the two Connellsville, Pa., districts in output. Mr. Parker states that "chemically the Flat Top coke is superior to that of Connellsville, as it is lower in mineral content or ash, and it is regarded by some iron masters as equal in physical properties to the Connellsville coke." The Flat Top field includes the ovens in the Pocahontas coal field, and with it the U. S. Survey includes the statistics of the Tug River district, just to the west, where, according to Parker, the United States Coal and Coke Company completed over 2,000 ovens to close of 1907.

Dr. I. C. White[14] gives the following average analyses of the Pocahontas coal and coke as made by B. H. Hite:

	Coal.	Coke.
Moisture	0.23	0.09
Volatile matter	17.43	0.98
Fixed carbon	77.71	90.99
Ash	4.63	7.94
Sulphur	0.62	0.58
Phosphorus	0.0057	0.0061

In the New River district the coal coked in Semet-Solvay ovens, as tested by Pennock for a report by Charles Catlett, gave the following results:[15]

Yield of coal in coke	75.69 per cent.
Sulphate of ammonia (pounds per ton of coal)	19.58 or 0.979 p. c.
Tar, pounds per ton of coal	90.70 or 4.530 p. c.
Gas, cubic feet ton of coal	8,500

The coal and coke had the following composition:

	Coal.	Coke.
Volatile matter	26.16	0.89
Fixed carbon	69.64	93.79
Ash	4.20	5.52
Sulphur	0.63	0.46

[14] W. Va. Geol. Survey, Vol. II., p. 700.
[15] Quoted W. Va. Geol. Survey, Vol. II., p. 688.

The Sewell coal in New River district and its coke have the following composition:[16]

	Coal.	Coke.
Moisture	0.69	0.14
Volatile matter	23.95	1.06
Fixed carbon	72.04	91.26
Ash	3.32	7.54
Sulphur	0.74	0.75
Phosphorus	0.008	0.0095

The following analyses show the composition of the Kanawha district coke:[17]

	Cannelton.	Carbondale.	East Bank.	Powellton.
Moisture	0.13	0.12	0.40	0.05
Volatile matter	1.95	1.02	1.66	0.64
Fixed carbon	89.26	91.53	87.26	91.49
Ash	8.66	7.33	10.68	7.82
Sulphur	1.05	0.91	0.69	0.72
Phosphorus	0.0215	0.0135	0.0075	0.0013

In the Upper Potomac district at Thomas, Coketon and Douglas, in Tucker county, the Lower Kittanning coal proves a very valuable coking coal with the following composition:[18]

	Coketon No. 2 Mine.		Coketon No. 3 Mine.	
	Coal.	Coke.	Coal.	Coke.
Moisture	0.29	0.11	0.50	0.12
Volatile matter	23.15	0.44	21.42	1.17
Fixed carbon	70.53	91.27	70.76	88.68
Ash	6.03	8.18	7.32	10.03
Sulphur	0.65	0.62	0.59	0.74
Phosphorus	0.019	0.0460	0.021	0.0270

The Lower Kittanning coke at Junior and Harding and the Upper Freeport at Thomas, have the following composition:[19]

	Junior.	Harding.	Thomas.
Moisture	0.08	0.12	0.18
Volatile matter	0.90	0.87	1.43
Fixed carbon	84.97	82.62	83.87
Ash	14.05	16.39	14.52
Sulphur	0.94	1.24	0.70
Phosphorus	0.018	0.034	0.03

16 W. Va. Geol. Survey, Vol. II. p. 700.
17 W. Va. Geol. Survey, Vol. II. pp. 574, 590.
18 W. Va. Geol. Survey, Vol. II. pp. 486, 487.
19 W. Va. Geol. Survey, Vol. II. pp. 430, 431, 435.

In the Upper Monongahela district, coke is made from the Upper Freeport coal on Deckers Creek, above Morgantown, and has the following composition, according to the analyses of Maryland Steel Company:[20]

	Coal.	Coke.
Volatile matter	32.05	0.70
Fixed carbon	61.45	87.85
Ash	6.50	11.45
Sulphur	0.69	0.75
Phosphorus	0.165	0.109

In the manufacture of the coke, the upper portion of the seam is discarded, thus lowering the phosphorus percentage, as shown by the following Survey analyses:[21]

	Richard.	Dellslow.	Cascade.	Bretz.
Moisture	0.08	0.05	0.25	0.05
Volatile matter	0.34	0.30	0.88	0.33
Fixed carbon	86.70	84.80	84.18	86.46
Ash	12.88	14.85	14.69	13.16
	100.00	100.00	100.00	100.00
Sulphur	0.78	0.88	0.76	0.79
Phosphorus	0.07	0.08	0.02	0.01

The Pittsburg coal is used for coke in Harrison, Marion and Taylor counties, and the coke has the following composition:[22]

	Beechwood.	Montana.	New England.	Monongah, No. 3.
Moisture	0.18	0.02	0.15	0.48
Volatile matter	1.24	1.02	1.29	2.67
Fixed carbon	83.45	87.51	85.79	84.56
Ash	15.13	11.45	12.77	12.29
				100
Sulphur	2.17	1.12	1.81	1.86
Phosphorus	0.0265	0.0200	0.0300	.....

FLUXES.

To remove the impurities from ores, fluxes are added which render the ore more fusible, so that the heavier metal in the molten mass separates from the lighter impurities, which

20 W. Va. Geol. Survey, Vol. II. p. 418.
21 W. Va. Geol. Survey, Vol. II.-A. p. 586.
22 W. Va. Geol. Survey, Vol II. p. 223.

unite with the flux forming the slag. Blast furnace slag is essentially a double silicate of lime, and alumina which is more fusible than the single silicate of lime, or the silicate of alumina alone.[23] In the reduction of iron ores in the blast furnace, limestone or dolomite, or both are used as flux.

Limestone consists mainly of lime carbonate ($CaCO_3$), but it also contains various other elements or compounds as impurities especially silica and magnesia. Sulphur and phosphorus, while usually present, are seldom in sufficient quantity in limestones used as flux to be injurious. They should not exceed 0.02 of one per cent.

Silica makes a limestone more infusible and so if present in any quantity will increase the fuel requirement and cost of treatment. In some localities the limestone for flux is sold on a sliding scale basis on increase or decrease of silica from an agreed normal percentage of this element.[24]

For ordinary blast furnace work, the limestone should not contain over 4 per cent silica, and would be better under that percentage. It is used in small quantities as a flux in small cupolas where iron is melted for use in the Bessemer converter and also in open hearth steel but for these purposes, the silica should be under one and a half per cent.

The effect of magnesia in limestone used with iron ores in the blast furnace is a subject on which engineers do not agree. Bell,[25] for example, states that "lime at high temperatures has a certain affinity for sulphur, whereas magnesia has little or no action on it." If this statement is true magnesian limestone or dolomite would not be a successful flux in ores containing sulphur. On the other side, Phillips says[26] "it may be regarded as practically settled that as a desulphurizer in the blast furnace, dolomite is quite as efficient as limestone for ordinary grades of iron, and much more efficient for basic iron requiring unusually low sulphur."

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23 Huntington and MacMillan, Metals, p. 106.

24 Phillips, Iron Making in Alabama, Ala. Geol. Survey, 1898, p. 62.

25 Quoted by Campbell, Manufacture and Properties of Iron and Steel, p. 53.

26 *lot. cit.* p. 73.

The explanation of these differences of opinion on the part of practical iron workers is given as follows by Firmstone (quoted by Campbell, p. 53): A high content of magnesia tends to produce the formation of spinel, an infusible and insoluble compound of alumina, lime and magnesia. The formation of this compound depends upon the presence of a large quantity of alumina, as well as the presence of magnesia. If the ore contains a small proportion of alumina, a high percentage of magnesia will give no trouble. The proportion should be so regulated that when the slag from the furnace contains over 20 per cent magnesia it shall not contain over 10 per cent alumina. Campbell states (page 54) that whether this is the true explanation or not, it is certain that furnaces in eastern Pennsylvania, New Jersey and Alabama, have used for many years a limestone containing 5 to 20 per cent of magnesium carbonate, without any noticeable increase in the quantity of stone or fuel, and without any trouble from sulphur.

Phillips,[27] from his long experience in practical iron work in Alabama, finds that in the manufacture of basic iron in open-hearth steel furnaces, dolomite has decided advantage in the elimination of sulphur, but he is uncertain whether the advantage is due to the presence of magnesia or due to the fact that the dolomite is low in silica, not over 1.5 per cent, and also very uniform in composition. He gives the average composition of the dolomite used at Birmingham as

Silica, 1.5 to 2 per cent.
Iron and alumina, 1.00 per cent.
Lime carbonate, 54 per cent or Lime oxide 30.31.
Magnesium carbonate, 43 per cent. or Magnesium oxide 20.71.
Sulphur, below 0.11 per cent.

According to Uehling,[28] "in determining the value of a stone as a flux, it is not only necessary to deduct the impurities it contains, but in addition to that, as much of the base as is necessary to flux these impurities. What remains only can be considered as available flux, and has value in the

[27] Alabama Geol. Survey, 1898, p. 63.
[28] Report Iron Making in Alabama, Ala. Geol. Survey 1896, p. 65.

blast furnace. To estimate the available flux, we must deduct 2 per cent from the carbonate of lime for each unit per cent impurity in the stone. Taking the limestone at 96 per cent of carbonate of lime and deducting from this 8 per cent to take care of its own impurities, we have left for available flux 88 per cent of carbonate of lime." Uehling also computes the fluxing powers of magnesium and lime carbonate are to each other as 84 to 100.

In this country it is almost the universal practice to use raw limestone rather than calcined stone. Theoretically the calcined rock would be better, but practical tests show but little advantage and many disadvantages. There appears to be no question that the use of raw stone involves a large fuel loss, which is at present impossible to offset.

This loss of fuel value is caused as follows, as explained by Campbell (p. 54): Pure limestone would contain 44 per cent by weight of carbonic acid gas (CO_2) so the value of the stone as flux would be 56 per cent of the weight used. The carbonic acid gas is expelled at full red heat, but at this temperature the gas acts on the coke with reaction represented by the formula—

$$CO_2 + C = 2\,CO$$

so that each pound of carbon in the limestone absorbs a pound of carbon from the coke and carries it off in the gases. If 750 pounds of limestone are used for each ton of pig iron made, the stone will contain 90 pounds of carbon and will remove 90 pounds of carbon from the fuel, or about 110 pounds of coke. If the proportion of limestone is doubled for treating impure iron ores there will be a loss of 220 pounds of coke.

Calcining the limestone before use in the furnace to avoid the loss of fuel has proved a failure, according to Campbell. because lime oxide has a great affinity for carbonic acid at temperature below red heat. The calcined limestone is charged into the furnace at a temperature below red heat in an atmosphere containing carbonic acid which is always present in the furnace. The lime oxide takes again its content of this gas and is changed back to lime carbonate, the result

being the same as though raw limestone had been used. It is also found to be impossible to practically expel all the carbonic acid in calcining limestone. Bell[29] found that only about one-half of the gas was expelled in the process of calcination. Campbell also states that in the American practice of furnace use, such strong blast is employed that much of the finely divided calcined lime would be carried away with the gases, overcoming any advantage in fuel saving.

Use of Dolomite. In the basic Bessemer and basic open-hearth processes, the bottom of the furnace must be basic and is made usually of dolomite or magnesian limestone. While the dolomite rock is sometimes used in natural state, it is regarded as better practice to calcine the stone and then grind it and mix with coal tar. In the basic Bessemer process the vessel is lined with this mixture. The dolomite should have a low percentage of silica and a high percentage of magnesia.

West Virginia Furnace Limestone and Dolomite.

Near Martinsburg, West Virginia, is an area of high grade limestone equal to the best in the United States and superior to most deposits. This limestone covers a large area with a depth tested to 200 feet, and large quantities are shipped to the Pittsburg market, amounting to about 350,000 tons a year. The stone is low in sulphur and phosphorus, and with less than one per cent silica, as shown by the following analyses made in the laboratory of the West Virginia Geological Survey for volume III of the Survey reports:

	Baker quarry.	Bessemer quarry.	Clohan farm.	Engles station.	Rutherford farm.	Kline quarry.	Nicklas farm.	Nicklas farm.
Lime carbonate	95.44	95.18	96.82	98.21	98.25	97.17	98.98	99.36
Magnes'm carbonate.	2.51	3.47	1.29	0.86	1.41	1.26	0.43	0.23
Silica	0.60	1.14	0.69	0.02	0.73	0.60	0.58	0.79
Iron and Alumina..	0.69	0.81	0.62	0.75	0.41	0.46	0.88	0.31
Sulphur	0.12	....	0.07	0.09	....	....	....	....
Phosphorus	0.05	....	0.02	0.007	....	....	....	....

29 Quoted by Campbell, p. 55.

Dolomites of almost theoretical purity are also found in this same portion of the state, known as the Eastern Panhandle. They are found at various places in Berkeley and Jefferson counties. Four analyses are given, as made in the West Virginia Geological Survey laboratory, which are typical of the field:

	Baker	Millville. Quarry.	Millville (Harpers Ferry Lime Co.)	
Lime carbonate	54.72	55.00	55.00	54.00
Magnesium carbonate	43.18	45.00	45.00	46.00
Silica	0.05	0.40	0.30	0.53
Iron and alumina	0.89	0.41	0.57	0.47
Sulphur	none			
Phosphorus	0.15			

The quantity of limestone required to flux one ton of Lake Superior ores in the Pittsburg field is about 1,000 to 1,200 pounds. In 1907 the Pittsburg field made 5,800,000 tons of pig iron, which would require 3,480,000 tons of limestone.

In the manufacture of open-hearth steel, 180 to 200 pounds of high grade limestone are required to the ton of steel. In 1907, 11,549,088 tons of this steel were made, which would require over a million tons of pure limestone.

The following analyses show the composition of Pennsylvania limestones used as flux in the Pittsburg furnaces:

	Tyrone.	New Castle.	Open Hearth limestone.	Dolomite.
Lime oxide	50.0	53.22	54.50	31.00
Magnesium oxide	2.0	0.61	0.85	20.50
Silica	3.82	2.50	0.75	0.50
Iron	0.44	0.64	0.72	0.15
Alumina oxide	....		0.13	0.35
Sulphur	0.05	0.04	....	0.02
Phosphorus	0.007	0.025	0.005	0.005

CHAPTER III.

THE ORIGIN OF IRON ORES.

The question of origin of metals and rocks is always one full of interest, and in many cases of the greatest importance in the determination of future permanency of supply. The question usually involves a variety of theories more or less in dispute, and more or less conflicting. The subject of origin of iron ores has long attracted the attention of geologists and engineers, and no report or treatise on iron ores is regarded as complete which does not include a study of the origin of the deposits. There has thus accumulated a group of theories of origin which is usually prolific of discussion.

To the person whose studies have been restricted to a local field a certain theory is often regarded as the key to the riddle of origin of all fields, and a theorem of geology is established at least in the mind of the investigator. To the student of different and often widely separated fields, one theory is not sufficient. It is a statement without dispute in modern time, that ores in different fields and sometimes in the same field have been formed in different ways. A plausible and accepted theory of origin of the Lake Superior hematite iron ores might find no application to hematite in West Virginia or Virginia. It would be a waste of time and energy to formulate a theory of iron ore origin to apply to all deposits. In a given locality there may be several possible explanations of iron ore formation, one of these will appeal strongly to one student, another theory to a second, and so on, and at the same time it may be impossible to prove any one of the theories to the exclusion of the others. The facts concerning the ores will be the same, but the interpretations or the conclusions drawn from the observed facts may be contradictory. As an illustration, iron ore is sometimes associated with a limestone, the stone wholly or partially removed. One theory

would explain the origin as due to removal of limestone in solution with resulting concentration of its iron content. Another theory would hold that as lime was removed, iron brought in solution from other strata takes its place, or a theory of replacement and the question remains which theory is the true explanation. A further discussion would center around the original source of the iron before it was in solution. Thus a given iron ore deposit is explained in a variety of ways, all more or less probable, or at least possible.

ORIGIN OF BOG IRON ORE.

There is one group of iron ores, however, the origin of which is explained by one theory, and practically all students of ore deposits agree upon the explanation of the origin of bog iron ores, found in marshes or bogs. Bog iron ores are forming at the present day and this formation can be directly observed. Wherever water circulates, it carries among other ingredients, iron; and wherever it comes to rest, iron is deposited.

Rocks, with almost no exception, clays and soils contain iron oxide, amounting to nearly 3.5 per cent in the total mass of sedimentary rocks, according to Van Hise. In fresh unweathered rocks, the iron is usually present in the form of ferric oxide ($Fe_2 O_3$) or hematite, which is nearly insoluble in water. In the process of weathering or decay, these rocks, especially where vegetable matter is present, undergo important chemical alterations.

The process of decay of vegetable matter is a process of oxidation of the carbon composing it. The required oxygen for this work may come from the air, but also from any minerals near at hand containing oxygen. The ferric oxide in the presence of the decaying vegetable matter gives up a portion of its oxygen to the carbon of the vegetable matter, and is thereby deoxidized, or as it is termed, reduced. By this reduction, the ferric oxide is changed to the ferrous oxide (FeO) represented by the following chemical reaction.

$$2\ Fe_2\ O_3 + C\ \text{(of vegetable matter)} = 4\ Fe\ O + CO_2$$

or a portion of the oxygen may come from the air,

$$Fe_2\ O_3 + C + O = 2\ Fe\ O + CO_2$$

The carbonic dioxide (CO_2) may escape into the air, or be partially taken up by water. The ferrous oxide is soluble in water, and unites with the carbonic dioxide in the water, being removed as iron carbonate,

$$Fe\ O + CO_2 = Fe\ CO_3$$

On evaporation of the water, or exposure to the air, the iron carbonate gives up its CO_2 to the air and takes oxygen from the air, forming the insoluble ferric oxide ($Fe_2\ O_3$) which floats as an irridescent, reddish scum on the surface until a sufficient amount accumulates, when it falls to the bottom of the basin, or bog, or spring, building up a deposit of ferric iron oxide. In contact with water, this oxide unites with a definite proportion of water, forming a hydrous iron oxide or limonite ($Fe_2\ O_3\ nH_2\ O$), a process known in chemistry as hydration. This process explains the glistening scum on many springs and is especially prominent in the so-called chalybeate or iron springs. It is sometimes described locally as an oily scum and is then looked upon as an indication of oil or petroleum, although it has no connection with oil and is not an indication for or against oil.

Where there is an excess of vegetable matter, the iron cannot be oxydized in the presence of the reducing vegetable matter, and the carbon dioxide is not removed, the iron, by evaporation of the water, is then deposited as iron carbonate. When the vegetable matter is mingled with the iron carbonate, a deposit of black-band ore may be formed. Some of these deposits contain enough organic matter to furnish fuel for treating the iron carbonate associated with it.

While there appears to be no controversy over this direct origin of bog iron ore, there are a number of modifications of this theory to explain the various deposits of sedi-

mentary iron ores. The relation of the crystalline iron ores, magnetite and hematite, to the hydrous oxide or limonite is also a subject involving a variety of opinions. Since magnetite is not a source of iron in West Virginia the following outline of theories of origin will be restricted to those applying to the other groups of iron ores.

THEORIES OF ORIGIN.

A systematic grouping of the various theories of origin of iron ores has been given by Julien,[1] who divides them into two main groups, of which the second is the more important, shown in the following outline:

A. Theories of Extraneous Origin.

1. Meteoric falls.
2. Eruption as dykes.
3. Sublimation into fissures.

B. Theories of Indigenous Origin.

4. Concentration from ferriferous rock or lean ores, by the solution and removal of the other predominant constituents.
5. Saturation of porous strata by infiltrating solutions of iron oxide.
6. Infiltration into subterranean chambers and channels.
7. Decomposition of pyrite and other ferruginous minerals enclosed in decaying schists, and transfer of the iron oxide in solution as ferrous sulphate.
8. Derivation from original deep sea deposits of hydrous ferric oxide, or of ferrous carbonate.
9. Deposit from springs.
10. Alteration of diffuse ferric oxide into ferrous carbonate.

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[1] Proceedings Acad. Nat. Science of Phila., 1882, p. 335, quoted by Winchell, Bull. No. VI. Minn. Geol. Survey, p. 224.

11. Metamorphism of ancient bog ores.
12. Metamorphism of ancient lake deposits.
13. Violent abrasion and transport.
14. Concentration and metamorphism of iron sands.

Winchell adds to this list the following groups:

15. True veins, formed by segregation or chemical secretion.
16. Electro-telluric action, as a result of the reactions and decompositions produced by electro-magnetic currents in the earth.
17. Substitution of ferrous oxide for lime in the original rock and change to peroxide.
18. Secondary product from the decomposition of basic rocks, eruptive or metamorphic; and concentration of the oxide of iron in drainage basins.

The first group of theories applies to limited deposits of rare occurrence, while the second group includes the theories explaining the more important iron deposits from an economic point of view and these theories will now be discussed.

4. *Concentration from ferriferous rocks or lean ores by the solution and removal of the other predominant constituents.*

By this method, soluble constituents might be removed, leaving the heavier and less soluble iron behind in a more concentrated form. A limestone containing iron oxide, by the removal of lime carbonate in solution, might result in the concentration of the iron oxide as a residual deposit. The weathering of the limestone in the eastern Pan Handle of West Virginia is marked by a deposit of red clay with 7 to 8 per cent of iron, while the unaltered limestone seldom contains over 1 per cent. Near Harpers Ferry in local beds of this red clay, the iron percentage rises to 10 or 12. But even in these examples of red clay, infiltration of iron by circulating waters has probably been equally if not more important than the residual accumulation of iron oxide from limestone disintegration or solution. Also as pointed out by Winchell, the oxide of iron would probably be removed by the circulating waters which removed the lime. The theory may apply to

certain local deposits where lean ores have lost more soluble contents and then made more concentrated.

T. C. Hopkins,[2] in his study of the Cambro-Silurian limonite ores in Pennsylvania, regards the source of the ores as in the Cambro-Ordovician limestone and slates, with smaller quantities from the overlying Ordovician and possibly Silurian strata, and the underlying slates and quartzites. The iron there being in form of carbonate especially, and also as pyrite and silicate.

The diffused iron was segregated into ore lumps by meteoric waters which collected in seams and cavities on and in the beds of slate, limestone and sandstone. "The deposits increase in size largely by the segregation of the oxide into the scattered nodular and flake-like masses in the underlying limestones, which are subsequently leached out, leaving the ore in residual material similar to that in the overlying clay ore mass which settles down upon it. The ore nodules and flakes may form at any point in the limestone, but the most favorable horizon for their concentration is at or near the contact of the limestone with an underlying bed of slate or sandstone, which forms a collecting place for the ores. The intercalated slates weather to a white clay, which thus forms the repository for many of the masses."

R. J. Holden,[3] in his review of the brown iron ores of Virginia states: "it seems probable that these ores are concentrations of iron which was originally disseminated in the Cambro-Ordovician limestone." These ores occur in residual clays and usually constitute about 7 per cent of this material.

Holden finds on analysis that the limestone contains 0.66 per cent of metallic iron, and that a thickness of 600 feet would yield a quantity of ore equal to that in the mine, but as several times 600 feet of limestone has been weathered, "it is unnecessary to look farther for the source of the iron."

The concentration of this iron formerly disseminated through the limestone has been by two methods. First *chemical,* through the alteration of the ferric oxide to the ferrous

[2] Bull. Geol. Soc. America, Vol. 11, p. 495; 1900.
[3] U. S. G. S., Bull. 285, p. 192; 1905.

condition whereby it became soluble and was carried downward a few feet by percolating waters to a point where it was oxidized and precipitated. Erosion then removed the leached portion until the ferric oxide was again within reach of the influence of vegetation, and the process was repeated many times, and the limestone wholly or partially removed.

The other method of concentration was *mechanical,* where the roof of a cavern in the limestone falls in, the iron residue follows, and surface waters pouring into the cavity, remove in suspension the fine materials and leave the lump ore. In some cases, limestone sinks have been an important means of concentration of the ore.

5. *Saturation of porous strata by infiltrating solutions of iron oxide.*

Winchell states that this theory was applied by Vanuxem in 1838 to explain certain ferruginous sandstones in New York, and also by Safford in 1856 to partly account for some of the Tennessee ores. The theory might explain the origin of some lean, sandy ores, but could not be applied to any rich deposits.

6. *Infiltration into subterranean chambers and channels.*

This theory is very clearly outlined by Nason[4] in his report. "If the water, carrying iron in solution, percolates through rocks and drips from the roofs of caverns, it becomes thoroughly aerated. The oxygen of the air at once attacks the iron and changes it to the insoluble form, leaving the iron hanging from the roofs of caves in the form of stalactites or falling to the floor builds up stalagmites. The process may continue until the entire cave is filled with *pipes* of iron ore in the form of limonite. Instead of this or in connection with it, let us imagine a moderately large stream entering a cave. The upper surface of the water is exposed to the air. The iron, as before, becomes oxidized, but in this case being heavier than the water it sinks to the bottom. If the supply be sufficient, the cave will be filled with the precipitated limonite and thus a *pocket* or deposit of iron will be formed."

[4] Iron Ores of Missouri, Mo. Geol. Survey, Vol. II, p. 187.

Lesley[5] states that the iron ores in Fulton and Bedford counties, Pennsylvania, occupy caverns eroded out of limestone. The ore was carried in solution as iron carbonate, and oxidation began at the time of or soon after deposition. While this theory may be applicable to certain deposits of limonite, it would not represent usual conditions, and would not apply to the larger deposits.

7. *Decomposition of pyrite and other ferruginous minerals, and transfer of the iron oxide in solution as ferrous sulphate.*

This theory of iron ores having their source in the decomposition of pyrite (iron sulphide $Fe\ S_2$) has been a popular theory, though perhaps more so in the past than at present time. It appealed very strongly to the Pennsylvania geologists of the Second Geological Survey. According to Winchell (p. 239), this theory was first advanced by Shepard in 1837 to explain the origin of the Connecticut limonites in the gneiss. Winchell regards the theory as a satisfactory explanation of some of the Minnesota limonites.

Frazer,[6] in 1875, applied this theory to explain the origin of the iron ores in York and Adams counties, Pennsylvania, and gives a number of observations and calculations to support the theory. He states that the supply of iron was probably obtained from the pyrite crystals of the lower slates. "The slates seem to merge by imperceptible degrees in a direction normal to the plane of bedding; first into completely metasomatized pseudomorphs (i. e. a complete change in composition but not in form) of limonite after pyrite; then, the same with a kernel of pyrite itself, first with a shell and then with a mere stain of ferric hydrate; and finally the same slates are revealed porphyritic from the pyrite, and not at all decomposed."

Frazer ascribes the origin of the iron in these limonite beds to the decomposition of pyrite in the slates rather than from pyrite in the limestone, as some have maintained. He finds the slates carry a considerable amount of pyrite, and by

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[5] Pennsylvania Geol. Survey, Summary Final Report, Vol. I, p. 425, 1892.

[6] Pa. Geol. Survey, Report C., pp. 137-143.

microscopical examination and computation estimates that there are 12.27 cubic inches of pyrite in every square inch of area, 5 feet thick. As one cubic inch of pyrite weighs 126.1 grains, one square foot of 5 feet thickness would weigh 31.81 pounds, or every mile of outcrop, with thickness 1,000 feet representing the arch above the present surface removed by erosion would represent 75,004 tons (2240 pounds). Frazer then estimates that in limonite, this would represent 79,711 tons for every mile of outcrop 5 feet thick and 1,000 feet of slope which was gradually carried down the dip and segregated among the clays. Making all due allowances for removal, loss, etc., with an actual thickness of the slates far greater than given above, Frazer states the pyrite would account for all the limonite found in this portion of the state.

Lesley in 1892,[7] accepts this theory of Frazer and computes that the Cambrian slates of Vermont which he had examined contain sufficient pyrite in an outcrop one mile long, 90 feet wide and 90 feet deep to make 1,500,000 tons of iron. He also states that even in slates without much pyrite, the percentage of ferrous oxide is 1 to 7 per cent, and would be sufficient to account for the great deposits of limonite.

In Franklin county, Pennsylvania, the ores found in the Silurian slates, according to McCreath,[8] resulted from decomposition of iron pyrites, "the larger percentage of sulphuric acid they invariably carry going to confirm this view."

According to Kemp,[9] the brown hematite ores with 40 to 41 per cent iron in Virginia are found in the weathered and oxidized surface zone above the pyrite deposits in Floyd, Grayson and Carroll counties in the southwestern part of the state, while below the water line, the ore is uniformly pyrite or pyrrhotite (magnetic pyrite).

Mr. P. S. Smith,[10] in a recent account of the gray iron ores of Alabama, which are hematite ores carrying some magnetite regards the original ore as limonite, but states

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7 Pa. Geol. Survey, Summary report, Vol. I, p. 206.

8 Pa. Geol. Survey, Report, MMM p. X; 1881.

9 Ore Deposits, p. 85.

10 U. S. S. G. S., Bull. 315, pp. 178-181; 1906.

that the limonite was not necessarily the original form in which the iron ore was deposited, and in some cases it represented the residual concentration remaining after the decomposition and oxidation of pyrite.

Mr. H. M. Chance[11] has recently elaborated this theory of pyrite origin, applying it to all large iron ore deposits. He regards the iron ore bodies as gossans underlaid by pyrite. This extreme view of pyritic origin is given in the following words by Mr. Chance: "All important deposits of iron ores occurring as magnetite, hematite, or limonite, in strata of sedimentary origin, are residues from the oxidation of sedimentary deposits of pyrites, excepting only the bog ores and the oxidized outcrops of carbonates.

"As a corollary of this proposition, it may be added, such deposits may be expected to continue in depth below the zone of oxidation as pyritic sediments, commensurate in size with the residual bodies of iron ore remaining in the zone of oxidation."

8. *Derivation from original deep sea deposits of hydrous ferric oxide, or ferrous carbonate, deposited either by chemical precipitation or by mechanical sedimentation.*

Many deposits of iron ores are found bedded with sedimentary rocks and sometimes show stratification planes and ripple marks, etc., characteristic of shore line formations. The theory that iron ores are original sea deposits was first advanced, according to Winchell, by Dr. Edward Hitchcock in 1833 and repeated by him in 1861, also stated by C. U. Shepard in 1837 and by J. W. Foster in 1849. Von Cotta, as quoted by Winchell, stated: "There can be no doubt that all true ore beds were originally formed by mechanical or chemical precipitation from water."

Winchell (p. 241) states that J. P. Lesley advocated the chemical precipitation of carbonate of iron to form portions of subterranean strata; and that the same explanation was given by B. S. Lyman; and also by R. D. Irving as applicable to the ores of the Lake Superior region, on the principle that

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[11] Pyritic Origin of Iron Ore Deposits, Eng. and Mining Journal, Vol. LXXXVI., No. 9, p. 408; 1808.

the ore and jasper were chemically precipitated from the ocean in about the same condition they have at the present time.

Chamberlin[12] describes the iron ores in Wisconsin as precipitated in an insoluble form and thus accumulating in beds, but he also states that the most probable explanation of massive iron ore beds is through action of organic agencies. More recent references to this theory will be given.

Weidman[13] explains the Baraboo iron ores of Wisconsin as original sedimentary deposits, because,

1. The iron ore deposits are bedded and to all appearances are stratified like other sedimentary rock deposits.

2. They grade into surrounding stratified rocks through all possible gradations, and the stratification of various kinds of rocks adjacent, are conformable to that of the iron ores.

3. Find shallow water evidences.

He regards the ore as originally limonite, later changed to hematite by dehydration under deep seated conditions of metamorphism.

Eckel,[14] in a preliminary paper on the Clinton iron ores of Alabama, outlines this theory as follows: "Original Deposition. The ores were formed at the same time as the rocks which enclose them, having been deposited in a sea or basin along with the sandstones and shales which now accompany them." He further states that he believes "the ores unquestionably originated at the same time as their inclosing sediments, and that, except immediately at the surface, they have been subjected to no later alterations or enrichments."

Burchard,[15] in his discussion of the Clinton ores of Alabama, states that the facts accord with hypothesis that the ore is the result of original deposition of ferruginous sediments. As to the theory of replacement, he says "that the ore is due to the replacement of limestone seems hardly

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12 Wisconsin Geol. Survey, Vol. I., p. 83.

13 Wisconsin Geol. Survey, Bull. XIII., p. 147.

14 U. S. G. S., Bull. 285, p. 172; 1905.

15 U. S. G. S., Bull. 315, p. 149; 1906.

possible when it is considered that instead of a decrease in percentage of iron and an increase in that of lime, with depth, until the bed becomes a limestone, almost the reverse has been noted. The lime in the bed is evidently an accessory deposit, as is the silica."

The limonite deposits of eastern Texas, according to Kemp,[16] are "derived from greensands, which consist so largely of glauconite, the double silicate of iron and potassium, and which are comparatively deep sea deposits. The formation of glauconite by precipitation from sea water, and as a filling of the small chambers in minute shells and organisms indicates a marine method for the concentration of iron oxide."

Spurr[17] found in the Mesabi iron district of Lake Superior area in the unaltered iron bearing rock, "rounded or subangular bodies made up chiefly of a green mineral, regarded as glauconite," and he regards the rock as an unaltered green sand, and therefore suggesting marine conditions. This theory tends to corroborate some of the early theories of marine origin of the Lake Superior ores mentioned above, and stated in a broad generalization by Julien[18] in 1882: "The strongly marked lenticular form and laminated structure of all deposits of crystalline iron ores—and even of the numerous smaller lenses, parallel or overlapping, which make up the large deposits—are unmistakably characteristic of marine accumulations. Neptune's own royal stamp."

9. *Deposit from Springs.* Around iron springs there accumulates a deposit of iron oxide mud which is regarded by many invalids as of high medicinal value in form of mud baths, but it is a doubtful source of economic iron ore. Lesley[19] ascribes the origin of many pipe ores to the evaporation of iron springs percolating through a mass of loose sediments or porous rock.

10. *Alteration of diffused ferric oxide into ferrous carbonate,* is a theory which Winchell (p. 245) states was proposed

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16 Ore Deposits, p. 87.
17 Quoted by Kemp, Ore Deposits, p. 129.
18 Quoted by Winchell, *loc. cit.*, p. 244.
19 Pa. Geol. Survey Summary Final Report, Vol. I., p. 425.

by W. B. Rogers, who "supposed that carbonate of iron was produced by the reducing action of organic matter brought in contact with it *in situ* in the rocks and not in infiltrating waters. Forces of segregation afterward accumulated it in irregular strata."

The remaining groups of theories as given by Julien and Winchell except 17, the replacement theory, and possibly 18, have been advanced to explain especially the origin of the crystalline iron ores, but have little or no application to the West Virginia ores. They are quite fully discussed in Winchell's report on the Minnesota iron ores.

17. *Substitution of ferrous oxide for lime in the original rock or the theory of replacement.*

The replacement theory of origin of the iron ores has always received more or less support and may be classed as one of the popular theories, undoubtedly true in many examples. The first statement of this theory so far found by the writer is by Dr. I. C. White[20] in his report on Lawrence county, Pennsylvania, in 1878, where he finds the Ferriferous limestone is replaced by iron at Houk's bank with a thickness of 22 feet of ore.

Dr. White states in this report that over the limestone is a persistent iron ore horizon over a wide area at many localities in western Pennsylvania, about one or two feet thick. Water charged with carbonic dioxide readily dissolves and removes the lime forming the fissures and cavities in which we now find the ore. The water flowing over the sheet of iron ore covering this limestone takes up the iron in solution, and then fully charged passes into one of these caverns near the outcrop, and redeposits the iron in the previously formed cavities, *or the limestone may have been removed pari passu with the bringing in of the iron.* Except for the last clause placed in italics by the writer, this theory would belong with Lesley's explanation under heading 6, infiltration into caverns or caves.

Dr. I. C. White again applies the theory in 1883 to explain the Clinton iron ores of Wyoming county and states,[21]

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20 Pa. Geol. Survey, Report QQ., p. 40.
21 Pa. Geol. Survey, Report G7., p. 231; 1883.

"The original rock is a hard and rather impure limestone filled with fossils, which near the surface has lost its lime through solution; the iron oxide being left in a soft spongy condition. As the bed gets below the action of surface waters it passes into hard ore or block ore which still contains a large proportion of lime. Still deeper the ore becomes too poor to work."

Dr. White gives a clearer statement of this theory in his report on Huntingdon county, Pennsylvania, in 1885:[22] "From the surface downward as far as the drainage waters can act upon the bed before issuing at the lowest springs in the neighborhood, the lime is leached out of the bed, leaving it a cellular or very porous siliceous stratum called soft block ore.

"The iron has evidently been *filtered into the bed* as the lime has been *filtered out of the bed,* otherwise the percentage of iron in the bed would not diminish below drainage level. Wherever the ore is valuable the enclosing rocks are very much weathered, the lime rocks are changed into clay, and the shales overlying and underlying the ore are bleached almost white, their iron having been presumably transferred to the ore bed. * * * * Any bed can become an ore bed provided it is so situated as to be a water bearer and recipient of the iron leachings."

Van Hise, in his Monograph on Metamorphism, which is a storehouse of information on the difficult problems of alteration of rocks and is full of valuable data on the problems of genesis of rocks and ores, calls attention to the replacement theory of iron ore origin for the Silurian limonite in the following description:[23]

"The Silurian limonites are largely replacement and concentration products of limestone, being therefore a result of metamorphism. In some districts the limestones originally contained a small amount of iron carbonate. * * * * Locally, the iron carbonate of the limestone has been picked up by the percolating waters. At various places these waters

[22] Pa. Geol. Survey, Report T3., p. 135.
[23] U. S. G. S., Monograph XLVII., p. 842; 1904.

have been converged at localities favorably situated. At such localities the iron is precipitated from the carbonate according to the reaction,

$$4\ Fe\ CO_3 + 2\ O + 3\ H_2\ O = 2\ Fe_2\ O_3,\ 3\ H_2\ O + 4\ CO_2$$

Often simultaneously with the process, lime carbonate ($Ca\ CO_3$) has been dissolved. Thus, at the surface of a limestone formation there may be produced a layer of limonite which passes downward into the limestone."

"In still other cases the iron of the limonite associated with limestones, has been in large part derived from adjacent formations. Such substitution is likely to occur where underground waters from different sources unite, as for instance where limestones are fractured."

The replacement theory has been used to explain the origin of the Oriskany ores in Virginia by J. E. Johnson, Jr.,[24] a trained engineer who has had a number of years' practical experience in the working of these ores. His theory is especially of interest since the ores are similar to the larger deposits in West Virginia.

Mr. Johnson regards the associated slates or shales as the original source of the ore, and finds that by chemical analysis, they contain 2.5 per cent of iron, and that a bed of the slate 200 feet, if completely leached, would yield a bed of iron ore 10 feet thick with 50 per cent metallic iron, and states that from amount of erosion of these slates, it is a wonder the present ore beds are not larger.

He explains the process as follows: "The water charged with carbonic dioxide ($C\ O_2$) dissolved the oxide of iron in the first place, and carried the iron until it came to the Helderberg limestone, and immediately deposited ore in order to dissolve the stone, the latter being more soluble in water containing carbonic dioxide while oxide of iron is less soluble. This brought the ore immediately under the sandstone (Oriskany) which, as far as its permeability would allow, acted like a sponge and absorbed as much of the iron oxide as it could hold.

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[24] Eng. and Mining Journal, Vol. LXXVI., pp. 231-232; 1903.

"As the process went on, the top portion of the limestone dissolved away leaving its insoluble contents behind This limestone contained considerable quantity of chert and more or less clay, which being insoluble gradually settled to the lower side of the limestone bed, where their support was no longer dissolved from under them. At the same time ore continued to be deposited at the top of the limestone and as that continually receded, the bed thickened until it came upon the immovable chert and clay which accordingly became the foot wall of the deposit."

Mr. Johnson regards the Oriskany sandstone as being but little involved in the change. He says that if the sandstone over the limestone was thin it acted as a matrix for the ore, but was later absorbed into the ore. While if thick the ore penetrated as fibers in the cracks of the limestone, but as the distance in the sandstone increases, the sandstone is not affected. He believes that the surface waters deposited the ore after the time of the mountain uplift for "the ore is not usually very deep and it may be taken as established that deposits of ore are found only under circumstances favorable to the action of large quantities of surface waters on the upturned and broken edges of (originally) great masses of black slate at points where the conditions favored the passage of the waters through the slate into the limestone." He gives a number of observations on the ore deposits to prove this statement, and regards the Coal Measure period as especially favorable for this work on account of the heavy rains and excess of carbonic dioxide in the air at that time. Outside of the objection that most geologists no longer believe in these unusual conditions of the atmosphere at that time, this explanation is in conflict with his date of the ore formation after the mountain uplift, since the uplift occurred after the period of the Coal Measures.

18. *Secondary product from the decomposition of rocks, and concentration of the oxide of iron in drainage basins.*

This theory, as stated by Julien, was restricted to the decomposition of basic rocks, eruptive or metamorphic, but

it can also be applied to other rocks, so the wording is changed as above.

Prime,[25] in 1874, in accounting for the origin of the limonites in Lehigh county, Pennsylvania, states that the iron ore bodies are underlaid by the compact damourite slates which only contain ore in their upper portion. He suggests, "that the damourite slates may have acted as an impervious bed to the waters containing iron in solution, causing these last to deposit the iron in and upon the slates.

Lesley states (*loc. cit.* p. 205) that "in some cases the ore seems to be a sediment with clay brought into a depression by inflowing waters which had passed through the slate rocks and obtained by a leaching process the iron which they contained, the clay being a decomposition of the feldspathic body of the rock."

This theory appealed to a number of the workers on the old First Geological Survey of Pennsylvania. In 1838 Dr. Robert Jackson[26] came to the conculsion that the limonite ores of Nittany Valley, Brush Valley, etc., belonged to the stratified limestone beds themselves, and had been set free from them by chemical and mechanical deposition, and were deposited in these valleys.

Professor John Frazer thought the ores were washed out of the surrounding sand rocks of the Medina, and had been collected in the hollows of the limestone surface of the valleys. Dr. Hitchcock, after a study of the brown hematite deposits of Vermont, Massachusetts and eastern New York, regarded these and similar deposits in the limestone valleys of the Appalachian belt as far as Alabama, as washed into their present resting place in a very recent geological age, the Tertiary.

In 1873 Dr. T. S. Hunt connected the easternmost range of these ores with chemical and mechanical dissolution of the iron bearing metamorphic slates of the Blue Ridge and Piedmont region. Lesley, after a review of these theories in

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25 Quoted by Lesley, Pa. Geol. Survey Summary Final Report, Vol. I., p. 206.

26 Quoted by Lesley, 2d Pa. Geol. Survey, Report A, p. 81; 1876.

the report of 1876, accepted Dr. Jackson's view of the limonite formation.

F. Prime, Jr., in his report of 1875,[27] repeats his theory of origin as given in 1874 and states: "The brown hematite is universally associated (in Lehigh county) with the damourite slates which, being impervious, would retain for a considerable period the waters containing the iron salts in solution and thus give these last a greater opportunity for precipitation. Large quantities of potassium exist in these slates and in free condition we know its energetic action in precipitating iron from many of its salts, it cannot be doubted that the potassium has exerted some important agency in the formation of the ores in their present position and condition."

This theory of iron bearing solutions depositing ore in a drainage channel where the floor is impervious, and with more or less reaction of two solutions is given in more detailed form by Professor Van Hise[28] to explain the origin of the Lake Superior ores. While the theory is given by Van Hise to explain the origin of these northern ores, and the facts supporting the theory have been taken from that region almost entirely, yet he suggests that "many of the Silurian deposits of the Appalachian region are at contacts of limestone with shale or slate. In some places these latter are certainly in such positions as to furnish impervious basements, and therefore the ores present many features analogous to those of the Lake Superior region."

Van Hise believes there can be no question as to the fact that the iron ore deposits in the Lake Superior region represent the work of descending meteoric or atmospheric waters, especially in the belt of weathering and even lower. As to the original source of the iron (p. 986), he finds iron is one of the most abundant elements in the igneous rocks, averaging about 4.64 per cent, while from Clarke's analyses and his own estimate of thickness of the different sedimentary

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[27] Pa. Geol. Survey, Report DD, pp. 49-53; 1875.

[28] U. S. G. S., 21st Annual , part 3, p. 336.
U. S. G. S., Monograph XLXVII., p. 1194.

rocks, the percentage of iron in these secondary rocks is 3.49 per cent.

The difference therefore between the iron in the two groups of rocks, 1.149 per cent, represents the loss of iron in the process of decay of the original rocks and the formation of the secondary rocks. Van Hise estimates that for the entire mass of sedimentary rock with this percentage of iron, there would be 7,155,750,000,000,000 metric tons of iron. He estimates that the processes of metamorphism have segregated 30 to 70 per cent of this iron in various iron bearing formations and in iron ore deposits. He further points out the important fact that while the ore deposits contain much the larger percentage of iron, the main mass of segregated iron is to be found in the iron bearing formations rather than in the iron ore bodies. Leith, in his study of the Mesabi ores, calculated that the amount of iron disseminated in the surface portion of the iron bearing formation of that district was probably 100 times as great as the iron contained in the valuable Mesabi ore deposits.

The disseminated iron in rocks has little or no value, there must be present some agency of concentration of ore into smaller and richer areas. This force is circulating surface water, and Van Hise states that at present time there is general agreement that these waters are descending and with ordinary temperatures. That the old idea of ascending heated waters bringing iron from the interior has been abandoned so far as iron ores are concerned.

The following paragraphs quoted from Van Hise's Monograph on Metamorphism (p. 1194) will make clear his theory of iron ore origin applied directly to the origin of Lake Superior ores, but which he believes may afford a reasonable explanation for many of the Appalachian iron ores:

The great iron ore deposits of the Lake Superior region rest on impervious formations usually in the form of pitching troughs forming the trunk channels of circulation; the impervious basement for an iron ore deposit may be an impervious sediment as slate or an igneous rock. The essential thing is that the basement shall be impervious to water as

compared with the iron-bearing formation in which the ores occur. The source from which the iron oxide is obtained is the original rock of the iron bearing formation either siderite or hydrous ferrous silicate.

As the water starts downward, the oxygen is exhausted in the oxidation of the ferrous carbonate producing ferruginous slates and cherts, and liberates the carbonic dioxide of the carbonates. The water from which oxygen is exhausted and which is enriched in carbonic oxide, is now able to take ferrous carbonate and hydrated ferrous silicate into solution. Where impervious basements exist in pitching troughs, the downward moving waters are deflected toward these and thus converged into such troughs.

Other waters more directly from the surface which have not come into contact with iron carbonate and iron silicate, and therefore bear oxygen, are also converged into the troughs. The mingling of these two classes of waters in the troughs results in the precipitation of the hydrated hematite and limonite, the reaction in the case of the iron carbonate ($Fe\ CO_3$) being,

$$2\ Fe\ CO_3 + nH_2\ O + O = Fe_2\ O_3,\ nH_2\ O + 2\ CO_2$$

Thus the ore deposits are the result largely of the transportation of iron carbonate to the pitching troughs, the iron there being precipitated by the mingling of the two solutions, and partly the result of oxidation of ferrous carbonate or silicate in place. Simultaneously with these processes the silica is dissolved and abstracted.

Where magnetites ($Fe_3\ O_4$) are found instead of brown hematite, Van Hise suggests they may be due to the direct precipitation from ascending solutions bearing iron carbonate, and descending solutions bearing an insufficient amount of oxygen for the transformation to the ferric oxide.

Mr. P. S. Smith[29] in his study of the gray iron ores of Talladega county, Alabama, suggested that the origin might be in part from decomposition of pyrite as given under the 7th

[29] U. S. G. S., Bull. 315, pp. 178-181; 1906.

group of theories above, but further states, "Second and probably most important source was limonite which was collected in certain horizons where relatively impervious strata succeeded relatively porous beds and so arrested the free circulation of the descending ore bearing solutions. These limonite beds were subsequently metamorphosed by the great folding and fault movements that the region suffered during the period of mountain building. Where metamorphism was moderate, and sufficient oxygen, limonite dehydrated to hematite. Where not sufficient oxygen to oxidize all the iron, limonite changed into hematite with some magnetite, the relative amount of the two minerals depending on the amount of oxygen present."

A study of the preceding groups of theories given by an observing and trained group of scientists, shows a wide difference of opinion as to the origin of iron ores, and readily suggests that different forces have been at work in the formation of this most valuable mineral product.

ORIGIN OF THE WEST VIRGINIA IRON ORES.

Clinton Fossil Hematite.

The origin of the Clinton fossil hematite is usually ascribed to the replacement of limestone by iron brought in solution, though Eckel and a few others have regarded the Alabama Clinton ores as original sea deposits formed at the same time as the enclosing rocks.

The Clinton fossil ore is found in widely separated localities, with similar structure, and with fossils preserved in it often in large numbers. There is a marked similarity in the ore of Wisconsin, Ohio, Alabama, New York, Pennsylvania, West Virginia, etc. Hand specimens from these different localities would be difficult to separate.

The theory of replacement would hold that the ores in these different localities were formed at the same period of geological time (Clinton), and under similar, if not identical conditions, giving an almost uniform structure and with fossils preserved in same manner. Such conditions did not

hold in the replacement of limestone by iron before nor since Clinton time, because other iron deposits, as for example the Oriskany ores, vary in structure and character often in the same limited area; and in the example cited, the fossils of the replaced fossiliferous Helderberg limestone have in all cases completely disappeared.

It may be assumed by the replacement theory, that in the case of the Clinton limestone alteration, the change was so slow and gradual that the fossil structures were preserved, but if so the limestone structure was lost for the iron ore has a distinct laminated structure, also a granular and oolitic structure quite different from the compact Clinton limestones. The ore also breaks in oblong blocks very different from the limestone. This might be explained as a secondary structure, the result of mountain-making forces, but the ore in Ohio has a similar structure where marked folding is absent. A slow process of molecular replacement which would explain the preservation of the fossil form, would at the same time preserve the limestone structure which is lost in these ore beds. The fossils in the West Virginia Clinton ore often have an outer shell of white lime carbonate which by theory of replacement should not remain.

The Clinton ore of West Virginia in Pendleton county has a flat scaly structure as if the iron particles had been rolled by wave or current action. In Grant county this structure changes to a granular and oolitic structure and the silica content is higher, increasing to the north at Keyser, in Mineral county, where the so-called iron ore contains 48 and 54 per cent silica. The Keyser ore would more properly be called a ferruginous sandstone. The fossils, however, are partially preserved, the rock breaks along parallel planes and by jointing into oblong blocks, a similar structure to the richer Clinton ores at the south. The relation of the bed to the surrounding rocks and its thickness are similar to the ore at the south. There is apparently an increase in iron and decrease in silica in this Clinton bed as followed south through Grant into Pendleton county.

At no place in this Clinton horizon are blocks of limestone or any trace of a limestone bed found in the deep ravines or mountain folds. If the ore was formed by replacement, the operation was most complete, involving a total change of the limestone and the percentage of lime carbonate in the ore averages only 1½ per cent and is often under one per cent.

The rocks of the Clinton series in this state are shales, clays, sandstone, and an absence of limestone. If there was originally a bed of limestone now replaced by ore, the stratum was a very irregular one, varying in thickness from 6 inches to 3 feet. It expanded and contracted from place to place in a most irregular manner; a relation very unusual for limestone, but often present in sandstones and other shallow water rocks.

By the theory of original sea deposition of this iron ore, it would be formed in the Clinton sea in same manner as the sandstone and shales. The iron was then precipitated and mixed with sand and clay in which fossils were preserved. The oolitic structure would imply a concretionary deposit, the iron being precipitated around sand grains in concentric form. In some portions of the sea, as in the Keyser area, there was only a slight precipitation of iron in the sand.

The difficult factor to account for in this theory is the quantity of iron available for this deposit in the Clinton sea, apparently not duplicated at any other time before or since. There must have been at this time an exceptional quantity of iron present; its source is difficult to explain. There are thus encountered in both theories factors almost impossible to account for; but it seems to the writer that the theory of original deposition offers a more satisfactory explanation of the origin of these West Virginia Clinton ores, than that of replacement.

Brown Hematite or Limonite.

The limonite or brown hematite iron ore beds are found near the contact of a limestone and sandstone with a shale

deposit above. The limestone along this contact has for the most part disappeared, only boulders here and there give evidence of its former existence. The iron ore is imbedded in fine shales or clays, and its upper wall is a sandstone into which stringers of ore may extend. In some places the lower surface of the sandstone is covered by a plate of ore varying in thickness from a fraction of an inch to 10 inches. In some of the deposits small blocks of sandstone are imbedded in the ore mass, and sandstone and ore are quite intimately mixed in other deposits.

The shales overlying the Oriskany sandstone above the ore bodies, have been estimated as 2,500 to 3,700 feet in thickness (U. S. G. S.). An analysis of this shale at the present time shows 4 to 5½ per cent iron oxide. Pyrite was not found in this shale, though it is possible that the unaltered rock may contain this mineral. One square mile of this shale 3,000 feet thick with 5½ per cent iron oxide would contain 356,495,040 tons of iron oxide, while the total tonnage of iron ore in Hardy county is only estimated at 100,000,000 tons. With this large quantity of iron oxide present in the weathered rocks, the loss of shales by erosion, and the loss of iron in the weathered shales would be more than sufficient to account for the present iron ore deposits, if the iron was concentrated in this Oriskany-Helderberg contact horizon by some geological chemical agency.

Circulating ground waters would contain iron taken into solution in its passage through the shales and would pass through the Oriskany sandstone until it reached the Helderberg limestone. The iron water would dissolve the lime carbonate, leaving its iron thus replacing the limestone to a greater or less depth. Probably more lime would be removed than is replaced by iron, so that the resulting formation would be porous. This Oriskany ore is characterized by its porous or honey-comb structure, and it often shows a concentric shelly structure characteristic of minerals formed from solution.

Blocks of the overlying sandstone would sometimes be caught in these limestone cavities, and later be completely

enclosed in the iron. In some deposits the ore next to the sandstone is very sandy and consists of a mixture of sand and ore, a structure well shown in the old Warm Spring mine on Capon Furnace tract, Hardy county.

The ores are not deposited in the Oriskany sandstone but in the place of the Helderberg limestone and, as Eckel pointed out in his Virginia ore studies, would be more correctly named Lower Helderberg iron ores. Since the resistant Oriskany sandstone forms a good guide to the location of this ore horizon and since the term is so well established in geological literature and among mining operators, it seems best to retain the name Oriskany ores. These Oriskany ores in West Virginia are regarded as due to limestone replacement by iron.

CHAPTER IV.

THE METALLURGY OF IRON AND STEEL.

CHARCOAL BLAST FURNACE.

The early blast furnaces of this country were designed for the use of charcoal fuel. They were built of native stone, usually limestone or sandstone, 30 to 40 feet high, though a few more modern furnaces reached a height of 85 feet. They were square in section 15 to 20 feet in size, tapering toward the top, and in many places were built against a bank or hill with top level with the bank so as to facilitate charging. The old furnaces in West Virginia were built some distance from the bank and connected by a broad platform bridge. In the interior they were lined with fire brick and made widest in the bosh, 10 to 12 feet in diameter, tapering below in the hearth to 3 or 4 feet and gradually toward the top to about 3 feet.

The hearth in the Ohio furnaces[1] was 4 to 6 feet high with diameter at bottom of 2 to 3½ feet. (See figure 1.) The Capon furnace, in Hardy county, West Virginia, had the hearth 5 feet high, 22 inches diameter at bottom and 24 inches at top with two tuyeres for air blast, 17 and 18 inches above bottom of the hearth with a 2¾-inch nozzle and air pressure of ½ to ⅝ pounds. An arch was made near the bottom of the furnace on one side with its lower part closed by a dam-stone 14 inches high, and the metal was tapped through a hole in the bottom of this stone while the slag passed through a notch at the top and flowed down over the ground and, after cooling, was carted away.

The bosh above the hearth in the Ohio furnaces was 9 to 12 feet high with diameter 9 to 12 feet. The stack above

[1] Data on Ohio furnaces from Lord, Ohio Geol. Survey, Vol. V., pp. 503-513.

the bosh was 22 to 50 feet high with diameter at top of 2½ to 3½ feet. The blast used in these furnaces was one of three kinds, cold blast of ordinary air, warm blast, or hot blast. The latter two had the air heated in special stoves, or the hot gases from the stack were drawn off through a pipe to a stove or furnace located at level of top of the stack and fitted with vertical or horizontal pipes. Cold air was admitted and drawn off below, heated and forced through the tuyeres. The temperature of the blast in this method was about 700 to 800° F., according to Lord.

The furnace was filled from the top by introducing a weighed quantity of ore and limestone forming the charge, and a measured amount of charcoal, the fuel and charge forming alternate layers. In starting the furnace it was customary to first place 30 to 35 blank charges of charcoal for burning the lower part of the furnace to the required temperature. The Capon furnace, in West Virginia, during the first week after starting produced 10 to 12 tons of pig iron a week, and under exceptional conditions 18 to 20 tons a week. The average charge for producing one ton of pig iron was about 174 bushels of charcoal, 1,558 pounds of limestone and 5,172 pounds of ore. This ore had the following composition, according to an old analysis given by Guerard:[2]

Iron sesquioxide	64.287
Manganese binoxide	7.680
Silica	11.771
Alumina	3.184
Lime	2.657
Magnesia	1.141
Phosphoric acid	1.110
Sulphuric acid	1.180
Water	6.695
Loss	0.295
	100.00
Iron	45.00
Phosphorus	0.483
Sulphur	0.472

In West Virginia there have been a considerable number of old charcoal iron furnaces scattered over the state.

[2] Resources of West Virginia, by Maury, 1876, p. 269.

but most of these have been destroyed, and a pile of loose rock with a small remnant of the stack marks their original site. The smooth and uniform cut blocks of stone were regarded by the farmers as more valuable for foundations of houses and barns than to be left in the original stack. In Hardy county two of these old furnaces are standing in fairly good state of preservation. The Crack Whip furnace, seven or eight miles southwest of Wardensville, and the Capon furnace six miles south are well preserved. The old furnace at Bloomery in Hampshire county has the stack in apparently as good condition as when it was in use. The records of the old works are difficult to locate but a number of the books of the Capon furnace have been preserved and were kindly loaned by Messrs. Volney and DeVan Keller, sons of the former proprietor and who now own the property. From the blast furnace book the following records were taken of two weeks run in 1869, and one week in 1870:

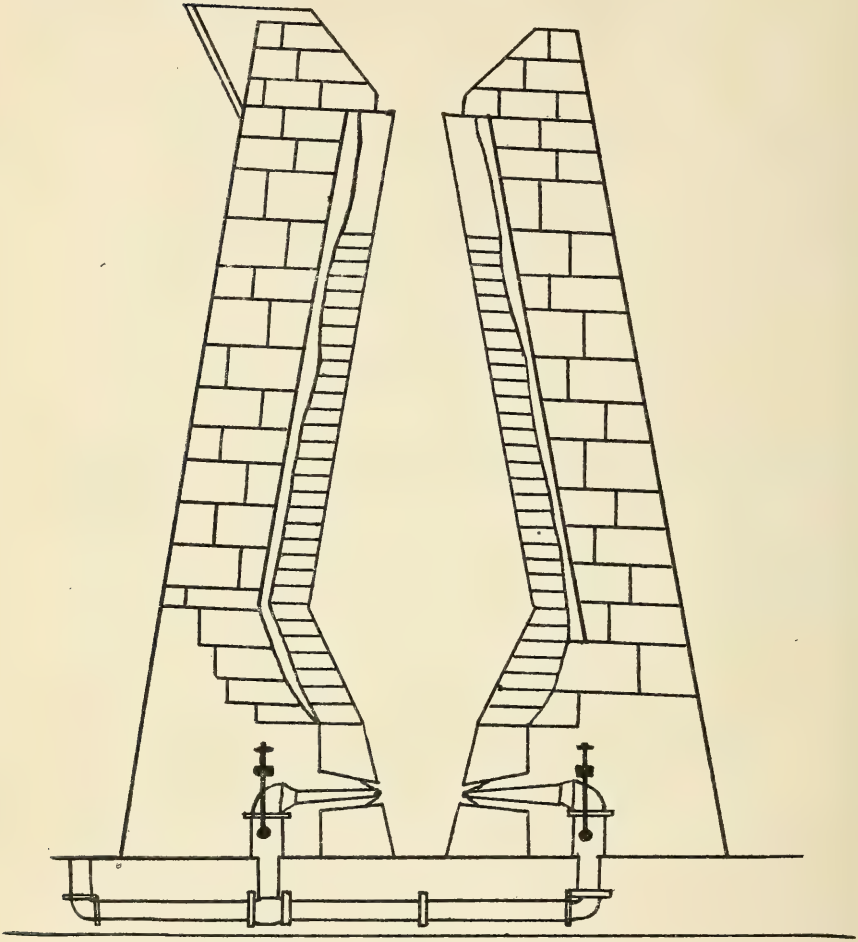
Nov. 1869.	No. charges.	Bushels charcoal daily.	Weight ore in pounds per charge.	Pounds of ore daily.	Limestone pounds per charge.	Limestone pounds daily.	
Sun., 21	20	280	450	9,000	100	2,000	
22	26	364	400	10,400	100	2,600	
23	27	378	500	13,500	100	2,700	
24	30	420	450	9,000	100	3,000	
25	31	434	400	12,400	100	3,100	
26	21	294	400	8,400	100	2,100	
27	26	364	400	10,400	100	2,600	
28	19	266	400	7,600	100	1,900	
29	26	364	400	10,400	100	2,600	
30	25	350	400	10,000	100	2,500	
Dec. 1	28	392	400	11,200	100	2,800	
2	32	488	400	12,800	100	3,200	
3	25	350	400	10,000	100	2,500	
Sat., 4	17	238	400	6,800	100	1,700	
—	—	—	—	—	—	—	23 tons pig made
	353	4,942		141,900		35,300	
July, 1870.							
Sun., 24	10	140	400	4,000	100	1,000	
25	23	322	400	9,200	100	2,300	
26	24	336	400	9,600	100	2,400	
27	24	336	400	9,600	100	2,400	
28	20	280	400	8,000	100	2,000	
29	22	308	370	8,000	100	2,200	
30	23	322	370	8,000	100	2,300	11 tons pig made
—	—	—	—	—	—	—	
—	146	2,044		56,400		14,600	

From the records, the weekly production of pig iron in tons in 1870 was:

19½	14	13¼	15¼	14½
21½	14	12	14	16
16½	13	12½	12	17

From a study of the records, the following charges were determined at different times, to make one ton of pig iron:

DATE.	Bushels Charcoal.	Pounds Limestone.	Pounds Ore.
December 5 to 11 inc. 1869.....	215	1,534	6,170
December 19 to 22 inc., 1869..	150	1.069	4,615
January, 1870...............	209	1,561	6,060
February, 1870..............	190	1,352	5,991
February, 1870..............	190	1,605	6,026
March, 1870.................	174	1,558	5,172
March, 1870.................	169	1,493	5,184
May, 1870...................	201	1,491	6,323
1870....................	188	1,345	5,567
1870....................	191	1,637	5,619
1870....................	175	1,248	4,992
1870....................	152	1,084	4,337
1870....................	200	1,505	6,379
1870....................	201	1,491	6,323
Average	186	1,426	5,697



,**Fig. 1. Section of Howard Charcoal Furnace in Ohio (after Lord).**

The shape and arrangement of these old charcoal furnaces may be illustrated by figure 1 taken from the Ohio Geological Survey report (Vol. V. p. 504.)

Forge or Bloomery. Some of the old charcoal furnaces were equipped with a forge and steam or water power hammer whereby the pig iron was forged into a square block or a bar called the "bloom."

COKE BLAST FURNACE.

The blast furnace is now practically the universal method of reducing iron ores to metallic iron. In it is placed the charge of ore, flux and fuel and from it come pig iron, slag and gases. The following description of a modern blast furnace using coke fuel is based on that of Mac Farlane.[3]

The modern blast furnace is a tall upright cylinder, covered by iron or mild steel plates and with an interior lining of fire brick. (See figures 2 and 3.) It rests on a firm concrete foundation, and the main body of the blast furnace is supported by cast iron hollow columns surmounted by a lintel of heavy cast iron or steel plates which carries the weight of the brick work and also supports the casing of rivetted metal plates which in turn sustains the weight of the platform at the top, over which the furnace charges are carried.

In the interior, the furnace consists of the **hearth** or **well** of brick work at the bottom, which is built from the foundation up to the brick work of the next part, the **bosh** or working part of the furnace. Above the bosh is the **stack** or heat intercepting part gradually increasing in diameter to the top. The bosh contracts downward so that the materials which have descended to this part, may be held up until the fuel is burned away at or near the top of the bosh; and the then melted pig iron and slag gradually drop to the hearth or well. By reason of difference in density, the slag and pig iron separate from each other and are tapped out in a fluid condition from the furnace.

The inner lining of the furnace is composed of fire brick or blocks backed by brick of lower grade and separated from the metal sheeting by a narrow space filled with granulated slag. The bosh is usually lined with water-cooled metal plates. The top of the furnace has a cup and bell arrangement which closes the mouth except at the moment of charging. The hot furnace gases can thus be collected below the

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[3] Iron and Steel Manufacture, p. 188 and ff.

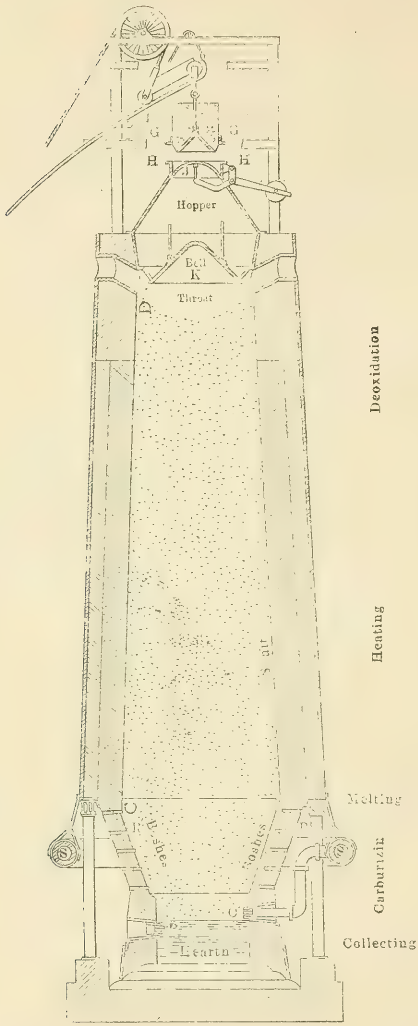

Fig. 2. Section of one of the Duquesne Blast Furnaces (Henry M. Howe in Eng. & Min. Journal).

GG, flanges on the ore bucket; HH, fixed flanges on top of the furnace; J, counterweighted false bell; K, main bell; O, tuyere; P, cinder ratch; RR, water cooled boxes; S, blast pipe.

bell and conveyed in pipes to be used for heating the air blast.

The cup is shaped like the wider portion of an inverted hollow cone, while the bell is made to fit the lower edge of the cup and is suspended from a balanced and weighted beam. The charge of materials is dumped into the circular-tapered trough thus formed, and over-balancing the weighted bell beam, the bell descends and the materials slip into the furnace. After the load is thus removed, the bell automatically rises and closes the mouth of the furnace. A hydraulic piston arrangement prevents any sudden downward or upward movement, giving a smooth and uniform motion. The size and design of the cup and bell (cone) must be carefully adjusted for a given furnace in order that the charge may be spread evenly in the furnace and not result in a piling of the lumps in the center or around the lining.

Blast. The air necessary to increase combustion in the furnace is forced in through **tuyeres** which project into the furnace at regular intervals and at a uniform level above the hearth. The air is forced by the blowing engines through stoves of special construction in which the air is heated. From the stoves, the heated air is forced through a large brick lined pipe or blast main and from this to the horse-shoe main which encircles the furnace. Pipes called goose-necks descend at regular intervals and conduct the air to the tuyeres through which the air is directly forced into the furnaces. The tuyeres are enclosed in water-cooled jackets to prevent their melting.

A fully equipped blast furnace will produce 300 to 700 tons of pig iron a day. Such a furnace, according to MacFarlane (p. 195), woud have the following dimensions:

Height of furnace.........	80 feet
Diameter of throat	14 "
Diameter at top of bosh...	21 "
Diameter at top of hearth..	12 "
Number of tuyeres........	8 to 16
Diameter of tuyeres.......	up to 6 inches

Pressure of blast..........10 to 15 pounds per sq. inch.
Temperature of blast......1,400° F.
Angle or slope of bosh.....about 75°

High blast furnaces require less coke for reduction of the ores than lower ones, but the height is limited by strength of fuel to support the charge. Eighty to ninety feet represent the ordinary working limit, though some of the Pittsburg furnaces are 100 feet high. The diameter must not be too great or the air blast will not reach near enough to the center of the charge.

Stoughton[4] states the diameter of the hearth should not be over 15 feet and that of the top of the bosh not over 22 feet.

In 1880 the Low Moor furnace,[5] in West Virginia, using brown hematite ore produced 559 tons of iron a week. Its size was as follows:

Height of stack	75 feet
Diameter of stack	9 "
Diameter at top of bosh	18 "
Number of tuyeres	8

At this time there were required to make one ton of pig iron:

Tons of ore	2.23,	costing $2.05	a ton,	$4.570
Tons of limestone	1.04,	costing 0.40	a ton,	0.416
Tons of coke	1.20,	costing 2.85	a ton,	3.420
Wages per ton				1.936
Total cost per ton iron				$10.342

Hot Blast Stoves. The stoves for pre-heating the air for use in blast furnaces are usually cast iron pipe stoves wherein the air can be heated to 800° or 1,000° F., or with regenerative system to 1,400° and 1,500° F.

A common type is the Cowper stove, which is externally a tall upright cylindrical shell with dome-shaped roof, and made of mild steel plates which are firmly riveted together

[4] Metallurgy of Iron and Steel, p. 60; 1908.
[5] The Virginias, Vol. I., p. 150.

to form a gas-tight structure. It is lined with fire brick and a fire brick flame flue or combustion chamber of elliptical section runs nearly the full height of the stove. Divisions at the lower part of this flue separate the gas into sheets so as to effect complete combustion with little excess of air. The rest of the interior is filled with fire brick so laid as to form hexagonal passages, making a honey-comb filling with the openings 6 or 7 inches wide and separated from each other by 2-inch walls. Cleaning doors are provided near the top, also man holes at bottom and one on top of the dome. Underground flues carry the blast furnace gases which are brought from the top of the blast furnace, and other flues carry the gas, after use in the stove, to the chimney. Valves are provided for regulating the gas and air supply and removal of the gases after use.

In the Whitewell stove the brick checker work is replaced by vertical fire brick walls alternately long and short, and its object was to render the cleaning operation easier. Both types are in common use. A blast furnace making 300 tons of pig iron daily should have four stoves, each 20 feet in diameter and 85 feet high, keeping the temperature of the blast at 1,000° to 1,400° F. (Campbell).

The volume of gas produced in a coke furnace has been estimated at 180,000 cubic feet per ton of coke with a temperature of 752° to 1,000° F.[6] The weight of the gases per ton of pig iron produced is given as about 7 tons. The composition of the gases from coke and charcoal furnaces is given as follows:

Reducing Gases	Charcoal Furnace.	Coke Furnace.
Carbon monoxide.............	25	28
Hydrogen	4	1
Marsh gas.................	1	0.25
Total combustible gases..	30	29.25
Inert Gases.		
Carbon dioxide..............	12	15.00
Nitrogen	58	55.75
	100	100.00

[6] MacFarlane, *loc. cit.* pp. 220, 221.

In the operation of the hot blast, the Cowper type for example,[7] blast furnace gas is admitted through the gas valve and air from the adjoining air valve, into the combustion flue which is already hot, and the gases ignite with a long flame extending upwards. The hot products of combustion are carried over and down the spaces in the brick filling, giving up heat to the bricks before being drawn off through the chimney flue. After the bricks are heated the supply of gas and air is turned off and air is forced through the hot blast valve at a temperature of 1,000° to 1,400° F., and is ready for use in the blast furnace.

When the stove is cooled down to about 1,000° F, the air valve is closed and the gas and air mixture brought in, and operation repeated. While one stove is heating, air for the blast is drawn from a second heated stove, and so on, thus requiring three or four stoves for a constant supply of heated air for the blast.

Working of the Blast Furnace.[8]

Into the top of the furnace is placed the charge consisting of ore, flux and fuel. (See figure 3.) From below through the tuyeres is forced the hot air from the hot blast stoves. As the air reaches the heated zone its oxygen unites with the coke fuel, producing a high temperature, and gases of combustion are formed, among which is carbon monoxide (CO) formed by the carbonic dioxide (CO_2) coming in contact with an excess of carbon in the highly heated fuel.

The carbonic monoxide gas rising through the stack comes in contact with the descending ore and takes from it oxygen forming carbonic dioxide (CO_2), thus reducing or deoxidizing the ore. The heated ascending gases also raise the temperature of the descending solids. At the top of the furnaces the gases are withdrawn and conveyed to the heating stoves or partly to gas engines for power.

The reaction of carbonic monoxide on iron ore, removing oxygen takes place first at about 250° C. (480° F.), but it is

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[7] Based on description by McFarlane, *loc. cit.*, p. 200.

[8] McFarlane, *loc. cit.*, p. 206.

not rapid until a temperature of 400° to 450° C. (800° F.) is reached, when the Fe_2O_3 is converted into Fe_3O_4 and then to Fe_6O_7.[9] The chemical reactions involved are given as follows by Campbell:

$$(1.)\quad 3\,Fe_2O_3 + CO = 2\,Fe_3O_4 + CO_2$$
$$(2.)\quad Fe_3O_4 + CO = 3\,FeO + CO_2$$
$$(3.)\quad FeO + CO = Fe + CO_2$$

Campbell states that each of these reactions produces heat, while the action of carbon on the iron ore beginning at about 400° C., (750° F.), absorbs heat and the reaction is represented by him as follows:

$$(4.)\quad Fe_2O_3 + 3\,C = 2\,Fe + 3\,CO$$
$$(5.)\quad Fe_3O_4 + 4\,C = 3\,Fe + 4\,CO$$
$$(6.)\quad FeO + C = Fe + CO$$

The flux and ore descending are gradually raised in temperature and the ore more and more reduced, reaching a maximum in the hottest zone of the furnace in the hearth where the reduction of the ore is completed. The iron and slag in molten state drop into the well of the furnace; the lighter slag floating on top is tapped off from time to time, while the pig iron is removed every few hours, and flows down a main channel in sand known as the "sow," and from this runs into smaller molds in the sand, forming the "pigs," which are about 3 feet long, weighing 70 to 100 pounds.

In the Pittsburg district, a blast furnace 80 feet high with total capacity of 18,200 cubic feet, working on ore with 59 per cent metallic iron, required for every ton of pig iron 1,882 pounds of coke, 1,011 pounds of limestone, 3,613 pounds of ore and produced 1,200 pounds of slag to the ton of iron (Campbell, p. 76).

From a study of the condition in a working blast furnace, the measurements of gases, observations of temperatures, etc., Campbell (page 80) determined the following conditions to be present:

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[9] Campbell, Manufacture and Properties of Iron and Steel, p. 64.

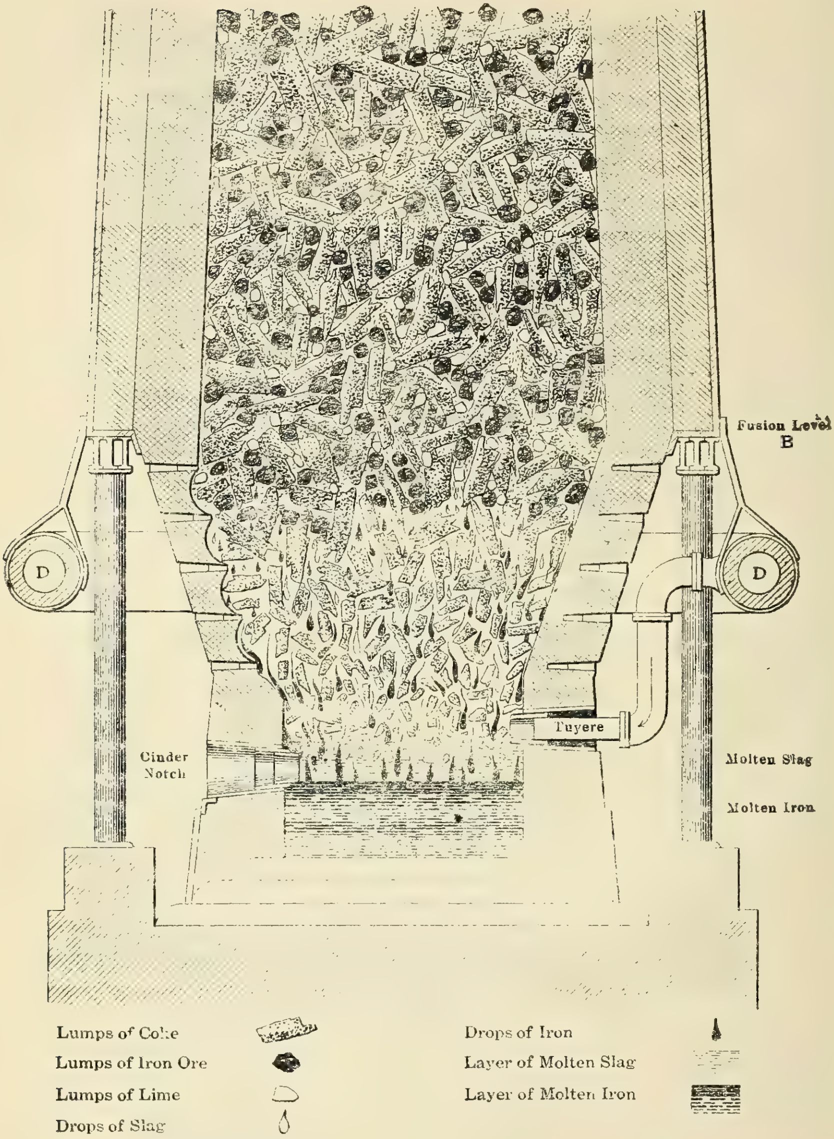

Fig. 3. Lower Part of the Blast Furnace (Henry M. Howe in Eng. & Mining Journal).

1. Of all the heat energy contained in the coke charged in a blast furnace, almost exactly one-half goes away in the tunnel gases, a small part as sensible heat, but most of it as unburned carbonic oxide (CO).

2. This proportion of heat so lost is about the same whether the furnace is working on lean ores with a high consumption of fuel or rich ores with a low fuel ratio.

3. The other half of the energy is used in reducing the iron ore, in melting the iron and slag, in losses from conduction and radiation, and in minor chemical reactions.

Campbell reaches the following conclusions as to heat distribution and requirements in a modern blast furnace:

4. The heat needed for the reduction of the ore calls for between 20 and 25 per cent of all the energy delivered to the furnace.

5. The fusion of the pig iron requires from 4 to 5 per cent.

6. The fusion of the slag requires 4.5 to 9.4 per cent, increasing with the amount of impurities and the quantity of stone.

7. The heat lost by radiation, in cooling, water evaporation in the coke, dissociation of CO, varies from 4.5 to 7.5 per cent, decreasing with a larger output of pig iron.

8. The heat required in reduction of metalloids, expulsion of carbonic dioxide from the limestone and reduction of this CO_2 to CO is 4 to 7 per cent.

9. The tunnel head gases remove 50 per cent or more.

In the working blast furnace, gases are removed from the top, slag and pig iron from the bottom. The slag is usually a waste product carried to dump piles, or it may be broken and used as road ballast. The lime silicate slag, free from injurious impurities, is sometimes used with limestone in the manufacture of Portland cement as at the Illinois Steel Company plant at South Chicago, and at Pittsburg. Slag of proper composition has been used after crushing as a natural or slag cement.

A study of the color of slag shows that the impurities have a marked and characteristic effect (MacFarlane):

Slags containing iron oxide (FeO) are black.

Slags containing manganese oxide (MnO) are brown or yellow.

Slags containing MnO and high silica (SiO_2) are green.

Slags containing much lime oxide (CaO) have cold stony appearance.

Slags containing much alumina ($Al_2 O_3$) are opalescent.

The pig iron is usually graded on basis of chemical composition and especially on the percentage of silica. Formerly it was graded almost entirely by the appearance of its fracture, a convenient though not always reliable method. The pig iron will contain the phosphorus of the ore, most of the sulphur of the ore and fuel, more or less carbon and silicon. MacFarlane states (p. 199) that the higher the temperature employed and the greater the proportion of fuel to the burden or charge of ore and flux, the more silicon there will be in the pig iron.

A considerable percentage of alumina will also aid in taking up silicon. This element is formed by reduction of silica (SiO_2) at high temperature by action of carbonic dioxide, and it enters into combination with the iron.

According to Campbell (p. 127) silicon, when present in large proportions reduces the total carbon, and whatever carbon is present, is mainly in the form of graphite, and toughens the iron. Manganese has the opposite effect, increasing total carbon and keeping it in combined form, making the iron brittle. Phosphorus increases fluidity of the iron, so is valuable in foundry iron, but increases brittleness.

The following analyses of pig iron are given by H. H. Campbell:[10]

[10] *Loc. cit.*, p. 127; analysis made by Hartman.

	Iron.	Graphite.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
No. 1 Gray.........	92.37	3.52	0.13	2.44	1.25	0.02	0.28
No. 2 Gray.........	92.31	2.99	0.37	2.52	1.08	0.02	0.72
No. 3 Gray.........	94.66	2.50	1.52	0.72	0.26	trace	0.34
Mottled	94.48	2.02	1.98	0.56	0.19	0.08	0.67
White	94.68	....	3.83	0.41	0.04	0.02	0.98

The above analyses may be compared with the following analyses given by Keep,[11] of the southern pig iron in Alabama:

PIG IRON.	Total Carbon.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
No. 2 Silvery........	1.51	0.58	0.93	4.91	0.58	0.08	0.25
No. 1 Silvery........	2.17	1.60	0.57	4.70	0.59	0.06	0.27
No. 1 Soft...........	2.94	2.11	0.83	3.65	0.60	0.06	0.27
No. 2 Soft...........	2.81	2.00	0.81	3.24	0.76	0.05	0.21
No. 1 Foundry.......	2.88	2.42	0.46	2.53	0.60	0.04	0.23
Foundry Forge.......	2.29	2.28	0.01	2.16	0.62	0.19	0.19
No. 2 Foundry........	2.16	1.90	0.26	2.00	0.79	0.08	0.23
No. 3 Foundry........	2.14	2.04	0.10	1.83	0.77	0.10	0.31
Grey Forge...........	1.79	1.51	0.28	1.74	0.70	0.17	0.38
Mottled	2.74	1.00	1.74	1.36	0.76	0.36	0.31
White	2.01	0.67	1.34	0.94	0.76	0.42	0.29

According to Keep (p. 192), pig iron is graded as shown below, by color, size of grain, or by percentage of silicon as indicated by analysis:

Ferro-Silicon includes irons which carry 10 per cent and over of silicon. The fracture is coarser than No. 1 silvery.

Flaky Silvery, named from appearance of its fracture, is made in a very hot furnace, and generally contains from 7 to 10 per cent silicon.

[11] Cast Iron, p. 195.

No. 1 Silvery is an open grained light colored iron, with over 6 per cent silicon.

No. 2 Silvery is of closer grain than No. 1.

No. 3 Close Silvery has a very close uniform grain, and has the ring of white iron. Its silicon is about 4.5 to 6 per cent.

In the grading of southern pig iron, Keep (p. 196) gives the following varieties and descriptions, included here for reference since the ores used are similar to the West Virginia ores:

"*Southern Silvery* is made when the furnace is very hot and is not a regular product. It is as good softener as regular silvery iron. The silicon ranges between 4 and 5 per cent.

"*No. 1 Soft and No. 2 Soft* are grades peculiar to a southern furnace. They contain too low silicon to be classed as silvery iron, and too much to be classed as foundry. If the fracture is close it is No. 2 soft. Both should contain over 3.25 per cent silicon, and the pigs have a smooth face.

"*No. 1 Foundry* is a choice grade having coarse grain and dark color. It makes fine-appearing and accurate thin and intricate castings. The surface of the molten metal is dark and sluggish looking, and does not give off sparks. Under the surface of the melted ore there are splashes of light. The pig has a blue velvet face where the surface is smooth.

"*No. 2 Foundry.* The fracture is lighter in color than No. 1, and usually the surface of the pig is smoother. The grain is closer and there is often a closeness around the edges of the pig. It is generally a little harder and stronger than No. 1 and it is not quite as fluid, as its carbon and silicon are generally less. The surface of the melted iron is a clearer red and throws off some sparks, splashes only a little as it cools, and its surface exhibits a series of lines or figures ever varying as though the surface were in circulation, such appearance continuing until the iron becomes pasty. The closeness of No. 2 may often arise from the way it is handled in the pig-bed, and it often has as high carbon and silicon as No. 1. It is generally as good an iron as is needed for the best foundry castings.

"*No.* 3 *Foundry.* The fracture is still lighter in color, the crystals are much smaller, and the fracture is smoother but contains some pits. It is stronger than the preceding grades. It contains less silicon and carbon than Nos. 1 and 2, and has not the same fluidity. The molten metal throws off sparks abundantly as it runs from the cupola. The surface figuring is less apparent than with No. 2. It is used in the foundry for heavy work, but will not take much scrap on account of its low silicon.

"*No.* 4 *Foundry or Foundry Forge* is a grade that is too close and with silicon too low for No. 3 Foundry and too open for Gray Forge. The surface of the pig has larger and more pits than No. 3.

"*Gray Forge* is known by its larger pits. It has too close a grain to be classed as Foundry Forge. It may be used to advantage for heavy castings.

"*Mottled* is the highest pitted iron that is made. The name does not indicate any grade, but a mottled appearance of grain formation. The iron may be quite gray, or it may be white with only a gray tinge. The latter would be highly mottled.

"*White* is made in a cold furnace, and carries more sulphur than any other grade."

The nature of the charges required in the working of southern ores is discussed quite completely by Phillips in the special report on Iron Making in 1898 for the Alabama Geological Survey (p. 139), from which the following notes were taken:

The largest furnaces in Alabama are 80 feet high and 19 feet 6 inches wide in the bosh, or widest part. The greatest amount of pig iron ever made in a furnace in one day was 265 and 315 tons. With 265 tons daily output, there were required 588 tons of ore, 62 tons of limestone and 265 tons of coke. The amount of ore required to make a ton of iron varies from 2.10 to 2.87 tons, the average being close to 2.50 tons. The average amount of coke used per ton of iron made is 1.41 tons of 2,240 pounds, the range being 1.16 to

1.60 tons. The average amount of stone used per ton of iron made is about 0.53 ton, the range being from 0.10 to 0.88.

The cost of making a ton of pig iron in Alabama in 1896, according to Phillips (p. 191), was:

Ore	$1.716
Limestone	0.128
Coke	2.735
Labor	0.966
Supplies	0.314
Current repairs	0.200
General expenses	0.093
Relining	0.200
Taxes	0.080
Insurance	0.006
Bad debts	0.030
	$6.464

He further states that the lowest cost that year was $5.74, the highest $6.84, and the average selling price of No. 2 Foundry was $7.22. These figures show a lower cost per ton of pig iron than at Low Moor furnace of Virginia in 1880, already quoted, which was $10.11 a ton of iron.

The above estimate of cost of materials in Alabama was based on the following prices per ton delivered at furnace (Phillips, p. 193):

Hard ore	$0.672
Soft ore	0.572
Brown ore	1.070
Limestone	0.647
Coke	1.727

MANUFACTURE OF STEEL.

Acid Bessemer Process.

The following description of the Bessemer process is taken from MacFarlane (page 64): The Bessemer process aims at the purification of melted pig iron or the correction of the quality by quickly blowing air through it in a vessel called a converter.

The modern Bessemer converter is a vessel formed of mild steel plates firmly riveted together and lined with a

refractory material to withstand the high temperature, the intense chemical action, the wear and tear. It is somewhat barrel shaped and has at one end an opening through which it is charged and discharged; at the other end are numerous openings or tuyeres through which passes the strong air blast. According to Stoughton, there are usually 18 to 30 tuyeres, each with 12 to 18 holes 3/8 to 5/8 inch in diameter.

Around the converter at its widest part is a heavy cast steel ring to which two axles or trunions are firmly attached, serving to support the converter and aid in its movements. One trunion is so arranged that it can be rotated to any desired inclination or position. The other trunion forms part of a blast pipe through which the heavy air blast is sent from the air compressing engine to the tuyere box under the bottom of the converter to be distributed to the several tuyeres. When the charge is de-carburized the vessel is turned so the molten iron lies on one side of the vessel and tuyere openings are above the level of the liquid; otherwise, stopping the blast, the molten iron would flow into the tuyeres.

The converters in smaller plants, according to Campbell, treat five tons of iron at a time, while in large plants, the capacity is 10 to 20 tons. The lining is made of stone, brick, or other refractory material, and is about one foot thick. According to Campbell (p. 157) the tuyeres are made of brick 20 to 30 inches long and with holes from 3/8 to 1/2 inch diameter. The total tuyere area varies at different works from 2 to 2.5 square inches per ton of charge. The blast pressure is 10 to 30 pounds per square inch. The heats are usually blown in from 7 to 12 minutes.

The iron is taken from the blast furnace to a mixer or receiver and from this is charged into the converter, or the pig iron may be remelted in small cupolas at the Bessemer plant. The cupola is usually 6 to 8 feet interior diameter and 20 feet high. The molten pig iron is run into the converter and blast turned on, and the flames and sparks are ejected. The vessel is turned to a vertical position and blast continued until the silicon and carbon are oxidized. When the operation is complete the converter is brought to a hori-

zontal position and the blast stopped. The charge is then recarbonized by deoxidizing the metal by the addition of a weighed quantity of hot ferro-manganese or spiegel-eisen, and is converted into mild, medium, or hard steel, by giving the requisite amount of carbon.

In making rail steel to contain 0.5 per cent carbon, for every 15 tons of blown metal about 3,000 pounds of melted spiegel-eisen are added. This quantity contains roughly 6 per cent carbon, 12 per cent manganese, 1.5 per cent silicon. For soft steel for wire, 500 pounds of spiegel-eisen are added to 15 tons of metal. For this latter steel the spiegel-eisen contains 7 per cent carbon, 80 per cent manganese and 13 per cent iron (Stoughton).

The loss in the blow is given by Stoughton as follows:

Carbon burned	3.5	per cent
Silicon burned	1.0	" "
Manganese burned	0.5	" "
7 per cent slag with 15 per cent iron	1.0	" "
7 per cent slag with 7 per cent iron pellets	0.5	" "
Volatilized and ejected	1.5	" "
	8.0	per cent.

The steel from the converter is poured into a ladle and from this into ingot molds. When cool the mold is stripped off and the ingots carried to storage room or to other parts of the plant to be rolled or cut into desired shape. The slag floating on top of the steel is readily separated in the ladle.

According to Campbell (p. 8), in the Bessemer process the air passing through the iron burns the silicon and carbon and the heat caused by their combustion is sufficient to keep the bath in a liquid state. If too much heat is generated, scrap iron or steam is added. The increase in temperature is due mainly to the silicon, and with present methods 1 per cent of silicon is sufficient. After the silicon and carbon are burned, manganese is added to render the steel tough while hot. For soft steel, ferro-manganese with 80 per cent manganese is added; but for rail steel pig iron with 12 per cent manganese is added. In the latter case, Campbell states that for every ten tons of steel about one ton of the manganese

pig iron (spiegel iron) is used, while for the soft steel a very small quantity of ferro-manganese is added. When the pig iron, and therefore the steel, contains less than one-tenth of one per cent phosphorus, the acid-Bessemer process is the cheapest method of making steel ever discovered (Campbell).

Basic Bessemer Process.

In the basic Bessemer process, steel is produced from pig iron with a percentage of phosphorus too high for successful use in the acid process. The essential difference in equipment from the acid process is a basic lining for the converter. This is usually made of a mixture of calcined ground dolomite (30 per cent or more magnesium carbonate and tar).

The silicon in the pig iron should be low or it will attack this lining, and the necessary heat in the operation cannot come from the burning of the silicon, but from the phosphorus, and this element must be present in amount of 2 per cent or more. The phosphorus is removed by combining with lime and going into the slag as lime phosphate.

In operation, a quantity of lime is placed in the converter with the melted basic pig iron, and the air blast turned on. The blast is continued until the flame drops, when the silicon and carbon are oxidized, as in the acid process. The blast is continued for the elimination of the phosphorus, and this stage is known as the after-blow. When the operation is complete, ferro-manganese or spiegel-iron is added, and after thorough mixture, the steel is poured into the ladle and from this into the ingot molds. The slag with its content of lime phosphate is used as fertilizer.

Campbell states (p. 11) that "the cost of labor, however, and the greater waste and diminished output of a basic Bessemer render the process out of question except where a suitable pig iron can be had at a much lower price than iron fit for the acid process. In the United States this condition does not exist and there is no plant in operation in this country."

OPEN HEARTH FURNACE.

According to Campbell (p. 186), the open hearth process refers to the melting of pig iron mixed with more or less wrought iron, steel, or similar iron products, by exposure on a hearth to the direct action of the flame in a regenerative gas furnace, and converting the resultant bath into steel, the operation being so conducted that the final product is entirely fluid.

A common type of furnace, though according to Campbell a type of poor construction, consists of a horizontal hearth, built of silica bricks and set over arches, the center two being air chambers and the outer two gas regenerators. All the arches are filled with fire brick laid in form of checker work, thus exposing as much brick surface as possible, and giving free passage for gas or air. The bricks absorb heat from the outgoing hot gases and give up heat to the ingoing cold air and gas when the currents are reversed.

In working the furnace, producer gas is conveyed through one of the gas arches, and air through the adjoining one. Both currents pass through openings into the hot furnace where they mingle and ignite, forming a long flame which passes over the hearth with rapid rise in temperature. Much heat is deflected from the roof of the furnace. The hot spent gases of combustion pass out through openings at opposite end of the furnace and are conducted through brick conduits to the top of the other set of air and gas regenerators, there imparting heat to the checker work of brick, and are drawn off at the bottom to the stack.

When the gas and air have passed through one set of regenerators for a given time, the valves are reversed, and the gas and air pass through the set of regenerators previously used and now cooled down. This regenerative system of pre-heating the air and gas before they reach the combustion zone gives an intense heat. With each reversal the furnace is more highly heated and the steel kept in a fluid condition.

According to Campbell (p. 190), the space occupied by the air and gas brick checker work combined should be at least 50 cubic feet per ton of steel in the furnace, while to secure the best results, this figure should be at least doubled. In a 50-ton furnace the checker brick in each arch or chamber should occupy at least 2,500 cubic feet, equivalent to a space 16x16x10 feet, with additional space above and below.

The pig iron is charged on the hearth and the gas and air flow regulated. In the early stages the silica, manganese and some iron, are oxidized and go into the slag. When the reduction is complete the metal is tapped off into a large ladle or receiver, and when half full the ferro-manganese is added,and the subsequent addition of more molten metal from the furnace stirs up the mixture and distributes the ferro-manganese through the mass, giving a fairly homogeneous steel (MacFarlane).

According to Campbell (p. 269) the area of the hearth for holding the charge is determined by the size of the furnace. The depth of metal should be 12 to 15 inches in a five-ton furnace; 18 to 24 inches with a charge of 30 to 50 tons. If the charge is too shallow on the hearth, the oxidation will be excessive, resulting in loss of iron, and if too deep, the rate of melting is too slow for good efficiency and daily output. The charge may consist of pig iron alone, or of pig iron and scrap steel.

Stoughton states that the standard size of open hearth furnace holds 50 tons and such a furnace has an inside length of 30 to 35 feet, width of 12 to 15 feet and maximum depth of 2 feet, though there is a tendency in America to increase the size to 60 or even 75 tons capacity. The smallest practical furnace would hold about 15 tons and then would be expensive in operation. In fuel requirement, according to Stoughton, the standard size furnace requires an average of 7,500 cubic feet of natural gas to the ton of steel, or 35 to 60 gallons of crude oil to the ton of steel. He estimates the yield of producer gas from coal as 150,000 to 170,000 cubic feet to the ton of coal.

Basic Open Hearth Furnace.

The basic open-hearth furnace, like the basic Bessemer process, has for its object the treatment of ores with too much phosphorus for acid methods. Like the acid process, the iron is melted and the silicon and carbon oxidized and partially removed, but the basic process in addition removes the sulphur and phosphorus by use of lime.

The essential difference in construction of the basic open-hearth furnace is its basic lining made of dolomite, magnesite, or other basic material, and most furnaces use the magnesian limestone or dolomite.

Lime or limestone is added to the charge, the use of the former lowers the heat absorption which is required in use of limestone to drive off the carbonic dioxide (CO_2). The use of limestone, according to Campbell (p. 283), has an advantage in the carbonic dioxide gas bubbling up through the mass, thus keeping up a motion favorable to chemical action, and also the carbonic dioxide aids in the oxidation of phosphorus, carbon, silicon and iron. From 8 to 30 per cent of lime is added with the pig iron and scrap, the exact amount depending on the purity of the metal charged.

The phosphorus unites with the lime, forming lime phosphate, which enters the slag and is so removed. When, by testing, the charge is found to be sufficiently free from phosphorus, the metal is tapped, ferro-manganese added and the metal cast in the molds. The composition of the finished steel is similar to the acid open-hearth steel. This process of treating iron made from ores with phosphorus too high for Bessemer steel, is especially adapted to the treatment of the southern ores as found in West Virginia, and which, under the Bessemer process, were of little or no value.

The basic slag in the basic hearth furnace thus serves the useful purpose of removing the troublesome phosphorus, which in acid processes enters the iron or steel. Certain precautions in the method are essential to successful work, and four of these are quoted from Campbell (p. 17) to show the character of the reaction:

A. "The oxide of phosphorus does not hold on with equal force to all bases. If it is combined with lime it is much harder to pull it back than if it is combined with iron.

B. "Since oxide of phosphorus acts as an acid and combines with a base, it is evident that a slag which is absorbing phosphorus becomes every moment more acid, and thus becomes every moment less capable of further absorption. * * *

C. "In the basic furnace the slag takes care of itself to some extent, but the cutting away of the hearth must not be allowed, and if phosphorus is to be eliminated, a sufficient quantity of lime must be added. Given the right amount of lime, there is then a considerable self-adjustment of the slag by the oxidation of the iron of the bath or by the reduction of the iron from the slag. If much lime be added, it will tend to drive the iron back into the bath, although it can never do it completely, while if little lime be added, there will be a greater proportion of iron in the slag.

D. "It is necessary that the slag shall be so basic that it will not attack the bottom. If it is so, it is basic enough to hold all the phosphorus that will be present if the stock contained only a moderate amount—say not over one-half of one per cent. If the stock contained far in excess of this, as often happens, special attention must be paid that phosphorus does not pass back into the steel when a high temperature is combined with violent agitation and perhaps a reducing action, these conditions being often present when the heat is tapped."

According to Campbell (p. 302), very little basic open-hearth steel was made in this country before 1890. In 1901, 3,618,993 tons of basic open-hearth steel were made in the United States. In 1906[12] the production was 9,649,385 tons, while the production of acid open-hearth steel that year was 1,321,613 tons, and 12,275,523 tons of Bessemer steel. The production of Bessemer steel increased 12.1 per cent over 1905, and open hearth steel increased 22.2 per cent.

[12] Eckel, U. S. Geol. Survey, Mineral Resources, 1906.

The following table from Mr. Swank's report shows the number of blast furnaces in operation in the United States from 1896 to close of 1907:

Year.	Bituminous Coal and Coke.	Anthracite or Coke and Anthracite.	Charcoal or Charcoal and Cok.	Total.
1896	105	32	22	159
1897	146	29	16	191
1898	152	30	20	202
1905	242	46	25	313
1899	191	68	30	289
1900	155	45	32	232
1901	188	54	24	266
1902	222	52	33	307
1903	120	29	33	182
1904	206	38	17	261
1906	269	48	23	340
1907	122	23	22	167

Dr. William Kent,[13] in a recent article, has illustrated the close connection between iron production and railway construction in the following table.

[13] Forty-two years in the Iron Trade, Iron Trade Review, Vol. XL., No. 2, p. 72; 1907.

PERIOD.	Average No. Miles R. R. Annually.	Total Production Pig Iron Tons.	Character of Period.
1860-1868 (9 years)............	1,493	....	Moderate development.
1869 to close 1873 (5 years)...	5,608	10,192,935	Violent development.
1874 to close 1878 (5 years)...	2,297	10,661,765	Long depression.
1879 to close 1883 (5 years)....	7,935	19,937,131	2d violent development.
1884 to close 1885 (2 years)...	3,449	8,142,344	Short depression.
1886 to close 1892 (7 years) ...	6,693	52,838,430	Rapid development.
1893 to close 1898 (6 years)....	1,940	53,277,939	
1899 to close 1906 (8 years)....	4,615	143,908,171	

Dr. Kent states that while fluctuations in railroad building were apparently the controlling influence on iron trade during the twenty years from 1868 to 1887, they then ceased to have such an influence. In 1900 the ratio of total amount of rails to the total amount of pig iron was 17.3 per cent. In 1905 it was 14.7 per cent as compared with 33.3 per cent in 1887.

CHAPTER V.

HISTORY OF THE WEST VIRGINIA IRON INDUSTRY.

The native iron ore industry in West Virginia has a past and future history, but not a present one. In a number of counties in the state the ruins of the old furnace stacks mark the sites of more or less successful iron enterprises. Some of the old companies failed as soon or before the stack was completed, while others were in operation down to a recent date, but practically all were closed down twenty-five years ago. Some of these furnaces began their history near the close of the eighteenth century and stand today over 100 years old.

In the early days down to 1855, these small charcoal furnaces scattered over the country east of Mississippi River, were able to work thin and often poor ores at a profit, and haul their output long distances by wagon to market. With pig iron selling at $60 to $80 per ton, with cheap labor, wide expanse of forests to furnish charcoal fuel, abundant water power, there was a wide margin for large incidental expenses, still leaving a good profit.

With few railroads through the country there was little advantage in the location of one furnace over another. A furnace back in the mountains of West Virginia would have an additional cost of transportation across the steep mountain roads over one located in a level area in Ohio, but the market of the Ohio ore was not the market of the West Virginia and Virginia ore. Railroads, however, have drawn the people of the country closer together and broadened the neighborhood of community of interests. Before the days of railroads the people 600 miles distant almost belonged to another world. But this distance, reduced from a 20-day wagon

journey to one day by rail brings in a wider market area but at the same time increases competition.

The early charcoal iron furnace hardly knew the meaning of the word competition, but when this element of trade with modern advantages entered, it soon caused their fires to be extinguished, and the furnaces stand as memorials to the early history of the American iron industry. Those furnaces with cheaper fuel or better grade of ore would crowd out others less favorably located, so that there was a gradual survival of the fittest until nearly all were crowded out of commission by the influx of Lake Superior ores.

The first cloud on the horizon for these furnaces was the completion of the Sault Sainte Marie canal in 1855, which gave an outlet to the lower lake ports for the boats laden with the rich ores from Lake Superior. The present iron tonnage through this two-mile canal is 55,000,000 annually. Later the Bessemer steel process was invented and perfected in the sixties, gradually becoming more and more important in the American steel industry, replacing in large part wrought and cast iron. The ores used at most of the charcoal furnaces were not adapted to Bessemer use on account of their high phosphorus.

In 1874 the total production of Bessemer steel in the United States was 191,933 short tons; reaching in 1876, 525,996 tons and in 1880, 1,200,000 tons when one-third of the pig iron produced was converted into Bessemer steel. The growth of this industry was slow from 1880 to 1885, averaging about 1,500,000 tons annually, which has increased at the present time to 12,000,000 long tons.

With the rapid increase in railroad construction, especially in the seventies, the cost of transportation of the Lake Superior ores from the lake ports was reduced. A new group of ores was now available at the coal and coke centers, a group of ores with high percentage of metallic iron, low percentage of impurities, and with a lower mining cost on account of the size of the deposits. Against this combination of qualities, the smaller furnaces were unable to maintain their trade. Iron dropped in price until its market

price was below the cost of production and transportation at the old furnaces.

For a time the high reputation of charcoal iron for car wheels and other special uses kept some of the furnaces in operation, but even this trade was finally lost by the cheaper production at other points. Here and there a charcoal furnace in some of the states has continued its work to the present time, but, as has been stated, the history of the West Virginia native iron industry ended in 1880 and 1882. Today there is not a blast furnace in the state working on native ores. In Virginia the charcoal furnaces were replaced by coke furnaces and connected by rail with the main line railroads, and the industry has survived, so that at a number of places successful furnaces are in operation.

West Virginia is always included in the list of pig iron producing states. The United States Geological Survey statistics for 1906 give three blast furnaces in operation at close of that year with a total production of pig iron that year of 304,534 long tons, an increase of 6,355 tons over 1905, and a production for first six months of 1907 of 151,643 long tons. These figures represent the iron industry of Wheeling, where Lake Superior ores are used. The history of the Wheeling iron and steel industry, as given in the following paragraphs, was prepared by the writer for the geological report on the northern Pan Handle counties (p. 9) forming the first volume of county reports of the present state survey.

About 1834 the "Top" iron mill at the north edge of Wheeling was erected by Schoenberger & Company as a bar mill, and made a few nails. It was called the Missouri Iron Works and operated by David Agnew. Later it was operated by Atchison, Bell & Co. as the Wheeling Iron and Nail Works, then changed to the Wheeling Iron and Nail Co., making 8,000 to 10,000 kegs of nails a week. The plant is now owned by the Wheeling Steel and Iron Co.

Some years later than the building of the Top mill, Bailey, Norton & Co. built a nail factory at the mouth of Wheeling Creek, about the location of the old B. & O. station. The site was later sold to the B. & O. railroad and the iron company erected the Belmont mill. The company afterward

dissolved partnership. Bailey and others built the LaBelle plant, while other members of the firm built the Bellaire mill. Kelley, Halloway & Co. erected the present Benwood mill with 240 nail machines.

There were at one time in Wheeling seven nail mills with 1,140 machines and an annual capacity of 2,830,000 kegs of cut nails, and the city was the greatest nail center in the world and widely known as the "Nail City." Then came the great strike of the nail machine workers, closing down the plants for a number of years. During this time the wire nail was invented and made on a large scale at Pittsburg, displacing the machine cut nail and the Wheeling factories were dismantled or abandoned, so that at the present time this industry is very small. The present iron and steel industry of Wheeling is concentrated in a few large plants.

The Wheeling Steel & Iron Company operates five mills; the Top and Belmont mills in Wheeling, the Benwood mill, the Benwood steel works and Benwood pipe mill. Their daily capacity is 650 tons of steel billets, 300 tons wrought pipe, 500 tons steel skelp, 100 tons of iron skelp, 50 tons of steel and iron sheets and 600 kegs of cut nails.

The Riverside plant of the National Tube Co., started in 1866 by Dewey, Vance & Co., consisted of a bar mill and nail factory, manufacturing light rails, bars, nails, and was later incorporated as the Riverside Iron Co. In 1870 furnace "A" was built and placed in operation in 1872. The steel works were added in 1884, and in 1887 the tube mill was completed, making gas pipe, casing, boiler tubes, bedstead tubing, hollow brake tubes for railroad use. In 1885 the large plate mills were erected to manufacture skelp for the tube plant. Furnace "B" was first used in March, 1903. The company now employs 3,000 men, with a blast furnace capacity of 700 to 800 tons a day. The skelp mill turns out 600 tons daily, and the tube mill 500 tons.

The LaBelle Iron Works Co. operates a large plant at Steubenville and a smaller one at Wheeling, the latter having a daily capacity of 250 gross tons of basic open-hearth boiler tube,skelp, nail and tack plate, and 1,000 kegs of cut nails.

The Wheeling Mold & Foundry Co. built their first plant in Wheeling in 1901, and now have three plants making especially chilled and sand rolls, rolling mill machinery and ingot molds. Three hundred to four hundred men are employed and the annual output amounts to about $800,000.

The history of the old furnaces working on native ores will now be given, but the accounts are of necessity incomplete.

MONONGALIA—PRESTON COUNTIES.[1]

The first iron ever made west of the Allegheny Mountains, according to S. T. Willey, was in 1789 at the old Alliance furnace in Pennsylvania, not fifty miles from Morgantown. In the following year work began at Springfield Furnace just beyond the Monongalia line.

Deckers Creek Iron Works were said to be standing in 1798, and an old record shows that John Stealey advertised for hands at this furnace in 1815. From 1815 to 1824 Watts and Kiger, sons-in-law of Stealey operated the furnace and in 1824 Watts was succeeded by Jesse Evans, who placed A. P. Wilson in charge and the furnace was known as the Valley. Alexander Clear and Wm. Alexander operated the plant sometime after 1851 and were succeeded by Clear. Crouther and French operated the works sometime after 1840 and were succeeded by James Kinsley sometime between 1852 and 1855, but he operated it but a short time. The works were located three and a half miles from Morgantown and included the furnace and a forge. The latter known as Rock Forge, had three fires, one hammer run by water power and made bar iron and was abandoned in 1855.

The Valley Furnace was 34 feet high with 8 foot bosh and made in 1851, according to Lesley,[2] 400 tons of railroad iron from ore mined within a circuit of one mile of the furnace.

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[1] Data from S. T. Willey, History of Monongalia County and History of Preston County.

[2] Iron Manufacturer's Guide of United States, by J. P. Lesley; 1859.

Cheat River or Jackson's Old Iron Works. Mr. Willey states that in an old deed of Nov. 28,1798, for a tract of land in Quarry run, the land is described as a tract upon which Pleasant Furnace is now standing. Samuel Jackson, about 1800, built here a dam and mill and sometime before 1809 erected a forge and made nails by hand. Pleasant Furnace, also known as Davis Furnace, not supplying enough iron for his use, he bought iron from Spring Hill and other furnaces in Pennsylvania, and a number of new furnaces were built, known as Woodgrove, Henry Clay and Anna; and the Greenville furnace was rented to supply iron for the Cheat River Iron Works. Samuel Jackson was succeeded by his son Josiah, who rented the works to Huston and others and then ran it himself, resulting in failure. Lazier, Bayard & Co. operated it a while, and April 22, 1839, Tassey, Morrison & Semple sold the works to the Ellicotts for $92,000, but they failed in 1848 or 1849. In 1852 McKelvey & Kay came into possession; and in 1854 Dr. Clymer took charge of the works for the Pridevale Iron Co., which failed about 1860. Smyth & Chess, of Pittsburg, were the next owners, and the last iron was made in 1868.

Samuel Jackson cut nails by hand until 1822, when he put in machinery. The Ellicotts built a rolling mill and a puddling and boiling furnace, a nail factory and a foundry. It is said, according to Mr. Willey, that they employed as high as 1,200 hands and fed daily for a time 3,000 persons, hands and their families. The rolling mill commenced work September 14, 1840.

Davis or Pleasant Furnace was probably built by John Davis and Hugh McNeely, who operated it for a time. John Jackson and Updegraff operated it until 1808-9, when they were succeeded by John Test, who failed in 1811 and the furnace was abandoned. This furnace made a ton and a quarter of iron a day, which was worth at that time $100 a ton.

Woodgrove Furnace was located three miles from Ice's Ferry, on the Ice's Ferry and Uniontown road. It was built by Josiah Jackson between 1822 and 1824 on the Samuel Canby tract of land, bought by Jackson in 1818. In 1836 it

was owned by Lamb, Tassey and Bissell, who were succeeded in 1839 by the Ellicotts, who added steam power. Claybaugh operated it from 1849 to 1852, when the old stack gave out, and he built the one now standing (1883). It was next operated by Dr. Meredith Clymer from 1854 to 1860, and he introduced the hot blast. In 1861-62 Henry S. Coombs and Isaac Blaney worked up the last stock. After the year 1849 all the iron made was shipped by water and the furnace was destroyed by fire in 1862.

Henry Clay Furnace. This was a cold blast furnace run by steam and located on a branch of Quarry Run four miles from Ice's Ferry. It was built by Leonard Lamb between 1834 and 1836 for Tassey and Bissell. It had a capacity of four tons in twenty-four hours. The next operators were Tassey and Church, succeeded by Tassey, Morrison and Semple, who sold it in 1859 to the Ellicotts. They built seven or eight miles of tramway and ran the furnace to about 1847. Up to 1839 all the iron made was boated down the river.

Anna Furnace, also known as the **River Furnace,** was located at Ice's Ferry, and was built by Ellicotts between 1845 and 1848 to burn charcoal, but was afterward converted into a coke furnace. Its capacity was eight to ten tons in twenty-four hours. It was bought by Mathew Gay in 1849 and sold to McKey and Kelvey in 1852, who operated it until 1854. Dr. Clymer then ran it to 1860, and from 1863 to 1866 it was in charge of John Kelley. In 1866 and 1867 it was worked by Lloyd and Lossing, and in 1868 Chess finished up the stock and the machinery was removed in 1881. Seven or eight miles of tramway were used at this furnace.

This furnace, according to Lesley, had a steam hot blast, and was 35 feet high with bosh 10 feet in diameter. In 15 weeks during the year 1856, Lesley states, 396¼ tons of iron were made from the Martin bank ore.

Clinton Furnace was located on left bank of Booths Creek, six miles above its mouth, and was built and named by William Salyards about 1846. The furnace was leased about 1848 to Robert M. Bendle and John Burns, who made

the first iron, but soon failed. It came into the possession of George Hardman about 1853, who used coke fuel and hot blast. About 1858 he failed and the property was operated by Benjamin Ryan, who made the last iron. The furnace, according to Mr. Willey, was a quarter-stack and has nearly disappeared.

Mr. Willey states that in 1790 Robert and Alexander Hawthorne came to Monongalia county and settled about four miles south of Morgantown, on Aaron's Creek, and built a nail factory one mile from mouth of creek before 1800, and operated it for a number of years. Lesley states this furnace was 32 feet high, with 8½-foot bosh, and in 15 weeks during 1856 made 32¼ tons of charcoal iron.

In Mr. Willey's history of Preston county a number of old furnaces are mentioned, and the following notes are taken from his book.

Greenville Furnace was located in Grant district, four miles from Bruceton and, according to Mr. Willey, is said to have been built by Walter Carlile at a cost of a barrel of watered whiskey, a box of home-made tobacco and a counterfeit ten dollar note. It was built about 1815, but soon failed through lack of capital. It passed into the hands of Miller and Frantz, and then to Fay, who failed. Next and last a Boston company, in 1836, with Harrison Hagans as president, ran it a short time. It is now torn down. (1882).

Valley Furnace was built about 1837 by Andrew Ochiltree and James Caldwell, who operated it two or three years. Both of these furnaces are said to have had sufficient ore, but long transportation and lack of capital caused them to fail. Valley furnace was standing in 1882.

Josephine Furnace was built on Muddy Creek, in Pleasant District, in 1852-3 by Harrison Hagans and called Virginia Furnace, and it was quite successful after the war. It was operated by George Maust, then by Lloyd and later by Landon. In 1879 it was run by S. B. Patterson under the name of Josephine Furnace, and work ceased in 1880. In Valley district, Scott and Dougherty, about 1825, started

the erection of a furnace at Deckers Creek Falls, two miles from Masontown, but it apparently was never completed.

Irondale or Franklin Furnace, in Lyon district, two and a half miles from Independence, was built about 1859 by George Hardman and was known as Hardman furnace. He ran it until 1865, when the Franklin Iron and Coal Co. came in possession and named it Franklin Furnace. In 1866 Hardman again ran it and in 1877 it was bought by Col. F. Nemegyei, who made extensive repairs.

On April 15, 1878, the first metal was made under the superintendence of Alex. Strausz and A. Evans. In the fall of 1878 Wm. Tate remodeled the furnace, increasing its capacity from 10 to 30 tons of iron in twenty-four hours. The blast was put in during June, 1879, and ran to July, 1880, when the furnace was repaired and ran until June, 1881, when work stopped on account of a strike of the laborers. Some repairs were made and blast started in October, 1881, and ran to 1882.

The furnace was 62 feet high, with 14-foot bosh, and made a cold-short pig iron for foundry use. Carbonate ores were used known as rock and shell ore with metallic iron reported as 37 and 50 per cent. There were 25 or 30 coke ovens supplying coke for the furnace and the power was furnished by a 150 H. P. engine.

Gladesville Furnace was built about 1870 by George Hardman and sold to Calhoun and Evans, who were followed by Tate and Lafferty in 1879, who operated it until 1881, since which time it has been idle.

The ores used in these old furnaces in the northern part of the state were found in the coal measure formations, and were usually carbonate ores of shallow thickness. The old openings have mostly fallen shut and it would be difficult to study them at present time. The ore used at the old Deckers Creek Iron Works or Valley Furnace, as it was later called, was a carbonate of iron replacing the upper part of the Upper Freeport limestone, which is found a few feet below the Upper Freeport coal on Deckers Creek above Morgantown.

This locality and furnace were visited by Professor Rogers in 1839 and described in his report for that year as follows:[3]

"*Lower Group of Ores.* In the lower part of the shales underlying the lowest coal seam, two bands of iron ore occur, each about a foot in thickness and separated by about four feet of shales. This ore, from its slight protection, is generally in a decomposed state, consisting chiefly of peroxide of a loose shaly texture, and therefore the more easily worked along with which a nodule of the original carbonate is occasionally found. Beneath the lowest of these two beds of ore is a white sandstone, 4 or 5 feet in thickness, and beneath this is a third bed of ore, generally 6 or 8 inches thick which, having been defended by the overlaying strata, has escaped decomposition, and displays its original character of a compact protocarbonate. A few inches below this in the shales, a fourth band occurs, 4 inches in thickness.

"Below this, separated by shales of unknown thickness, probably not more than 3 or 4 feet, occurs a band of limestone 5 feet thick, portions of which are quite rich, but the principal mass impure. From this station is procured the flux used at the neighboring furnace. This group of ores occurs very extensively on the western side of Laurel Hill, where owing to the gentle dip of the strata, being at about the same angle as the slope of the surface, these bands present themseves over a wide area on the western flank of the ridge, where they have been traced for many miles. As would be expected, owing to infiltrations from above, the ore at the bottom of the hill is generally richest.

"*Upper Group of Ores.* These ores occur much higher in the series, being above the second seam of coal. They rest upon a lead-colored siliceous and argillaceous sandstone, and are overlaid by siliceous slates of the same color which, being the first rocks of this kind met with above the second seam of coal, may serve as a landmark in searching for the ore. This ore is very variable in thickness, usually occuring in large nodules, sometimes fine grained, though generally coarse and siliceous, occasionally so as to resemble a coarse

[3] Geology of the Virginias, p. 371.

sandstone rather than iron ore. Indeed it frequently gives no indication of the presence of iron until after burning or long exposure. Like the ores of the lower group, it is explored over a wide area, being found within a short distance of the surface from the base of the hills to their summits."

Rogers, in 1839,[4] also described the ores at the Henry Clay and Greenville furnaces, which he says are found among the shales just over the Greenville limestone (No. XI) of the Lower Carboniferous. He says the ores occur in three different bands generally included in a section of 20 and always within 30 feet. He described the ore vein as follows:

"*The Upper or Castile Vein,* the most uniform in thickness varies from 8 to 15 inches, and having but a slight covering of shale has been less protected than the lower bands from atmospheric agencies. It is therefore usually found in a decomposed state, the whole bed sometimes presenting the condition of a friable shaly oxide, much valued on account of the ease with which it works. Occasionally it occurs in nodules merely encrusted with the oxide, the nucleus being in the original state of proto-carbonate.

"Beneath this, 8 or 10 feet, we meet with the *middle or rock vein* generally 8 or 10 inches thick, though varying from 4 inches to 3 feet. This is for the most part compact and undecomposed, more uniform in character than the other veins, and in general rich and fine grained.

"Below this, at a depth of about 8 or 10 feet is the *lower vein,* varying from 2 inches to 6, and averaging 4 inches. This is usually coarse and siliceous, and chiefly valuable at the outcrop, where it has been decomposed. All these ores contain vegetable impressions."

The Cheat River Iron Works described above, purchased in 1854 by the Pridevale Iron Co., and which failed in 1860, employed Prof. Wm. B. Rogers to make a thorough scientific report on the property in 1854. Prof. Rogers' report bears date of June 28, 1854, and the following paragraphs are taken from it:[5]

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[4] *Loc. cit.*, pp. 370, 371.
[5] *Loc. cit.*, pp. 679-705.

He states that after visiting every opening on the property and adjacent thereto, "the result of this extensive exploration has been the conviction that the Anna, Henry Clay and Woodgrove furnaces, can each command an adequate supply of ores of various compositions and richness, and that by a judicious mining of the better varieties, the products of the furnace and rolling mill may be impressed with the best qualities which the several uses of the metal demand."

The iron ores are discussed in much detail by Professor Rogers and he divides them for descriptive purposes into five groups, which he describes as follows:

Martin Group.

The first or lowest, called the Martin Group, is found in a mass of black and brown shales below the conglomerate with a total thickness of 40 to 50 feet. The lowest is the *Red-belt ore*, which lies a few feet above the first deposit of red shale under the great conglomerate and has been extensively mined by benching near the Henry Clay furnace. It is chiefly a hematite, probably 40 per cent metallic iron in selected samples. A quarter mile below the furnace, where the ore was worked by a drift now fallen in (1854,) Carr stated it was 18 inches thick of nodular carbonate. Rogers states "under a thick cover of rock, this bed would consist almost exclusively of the nodular carbonate, the hematite found along the outcrop being due to the modifying action of the atmosphere upon the exposed carbonate."

The second ore is known at the mines of the Henry Clay furnace as the *Martin ore,* and at those of the Woodgrove furnace as the Gum Spring or Ross ore. The Martin ore is separated from the Red-belt ore by 25 to 30 feet of flaggy sandstones and shales. "It has been wrought by benching in a winding line along the face of the hills around the sources of Quarry Run and other neighboring streams through a distance on the Pridevale property, which, continuously measured, would probably amount to two miles. In all these openings, I found, by the specimens left on the banks, that the ore is of nearly a uniform quality, being a blue nodular

carbonate of iron, of rather fine grain, covered with a rich scale of red oxide. The ore is imbedded in black ochreous shales, and consists partly of nodules, placed at irregular intervals in parallel horizontal courses, and partly of one or more layers of nodules, thicker and more closely placed. He found the total thickness of these iron ore seams to be 18 inches.

The Gum Springs or Ross openings in this ore furnished all the ore for the Woodgrove furnace, and the ore in character and association is similar to the last, with a total thickness of 15 inches. The next higher ore is the flint hematite, some 20 or 25 feet above the Martin ore, and in similar way it is enclosed in black and ochreous crumbling shales. It was worked by drifting and benching. It varies from one to two feet in thickness, a dark brown compact limonite or earthy hematite including nodules of clay. It rests on a two-foot mass of nearly flint rock which sometimes passes into an impure ore. The average thickness is given as 14 inches with 42 per cent metallic iron when properly freed from the earthy lumps.

Twelve to fifteen feet above the flint hematite is the *rock ore or England ore,* mined by drifts and benches, and near the head of Quarry Run forms a nearly horizontal sheet near the surface. It consists of large nodules of rich blue carbonate ore about 5 inches thick associated with the bluish rock ore made up of round granules imbedded in a bluish paste. It is an oolitic ore composed of a mixture of oxide and carbonate of iron and passes into an oolitic limestone. and the total thickness of iron ore is about 10 inches.

The highest ore of the Martin group is described by Rogers as "a meagre, flaggy ore intermixed with some good knots of brown hematite," and is mined by stripping or shallow benching.

Stratford Group.

The second or Stratford group of iron ores in Preston county, as described by Rogers, is found above the top of the Great Conglomerate. The first mass of hard rocks, 20

to 25 feet thick, above the conglomerate is a series of olive, buff or black shales, in which this group of ores is found.

The lowest ore is opened at Nick Carr's bank and is named the *Carr ore.* It is found 25 to 30 feet above the conglomerate, and in the Carr bank near Henry Clay furnace shows "in upper six or seven feet of the bench, scattered nodules of rich carbonate ore, and at the base, a bluish plate or flag ore in large oblong masses from 6 to 7 inches thick. It is a heavy ore found to work well at the Anna furnace, and promises to be persistent. Below the heavy plate is a layer of much poorer rock or sandstone ore, some 15 inches thick, and a few feet lower is a thin coal seam, the first met with above the conglomerate."

Twenty feet above the last and separated from it by a coal seam, said to be 3 feet thick in places, is the *Stratford ore.* It consists of three courses of flat nodules and large round masses of blue argillaceous carbonate, with a total thickness of about 10 inches. The mines have furnished a large amount of ore.

Twenty-five feet above the Stratford ore is the third or *blackband ore* in a mass of black and dark gray shale. Rogers states it is not a true black band but is named from the black shales enclosing the ore. There are two beds of it with total thickness of 8 inches, mostly carbonate of iron nodules Sam Coles mine embraces both sides Middle run, and shows at top scattered nodules and plates of sandy ore about two inches thick, and at bottom a layer 12 to 21 inches of poor ore.

Norris Group.

The Norris ore group as described by Rogers is found in the interval of 190 feet between the Stratford cliff rock and the four-foot coal above. The lowest bed of Norris ore is in the shales next above the cliff rock directly below the fire clay under the Norris coal, and is described as a brown oxide or earthy hematite of good quality.

Twenty to twenty-five feet above the Norris coal is the *limestone ore bed* but it was not worked and its value undetermined. Thirty feet higher is the third ore bed opened by

Clellan northeast of the Anna furnace, but the good ore seems to be limited in quantity, much of it being a ferruginous sandstone. Above this ore bed is the *Ashby ore* of the Woodgrove furnace tract, which has been extensively mined by benching around the face of the hill on the south side of the valley of Middle Run near the Woodgrove furnace; but it has not been mined for some years (1854), and was probably a brown oxide ore of good quality.

Haines or Snake Den Group.

Rogers states that this group of iron ores is included between the four-foot and the two and a half foot coal seams, an interval of about 180 feet. At the Anna furnace there were two belts, the lower mined under the name of *Haines ore* which lies in a mass of buff and olive shales twenty feet in thickness. It is a brown oxide or in places carbonate or iron, 6 to 14 inches thick. Rogers speaks of this ore as one of the most persistent in thickness, and one of the purest and richest brown ores met with in this region."

The upper belt, known as the *Snake-den ore,* is not well exposed at the Anna furnace but is an important bed at the Woodgrove furnace. It consists of a single course of massive rock ore, varying from 5 to 10 inches in thickness overlaid by crumbling shales and clays." It breaks into square blocks and is a bluish sandy rock highly charged with carbonate of iron, which is sometimes changed into red oxide and is high in carbonate of lime. Rogers states that this ore in its chemical and mineralogical character closely resembles the Scott ore, so productive on Deckers Creek and at Clinton furnace.

Big Coal Group.

This group of ores as classified by Rogers comes in the interval between the two and a half-foot vein and the Big coal or seven-foot vein, and is mostly limestone ore. The lower portion includes a number of thin ore seams which Rogers regarded as the product of decomposed ferruginous

limestone and shale near the surface, and concludes they would become poorer and more calcareous when followed under a deep covering of rock.

The upper ore belt is in the shales which extend 20 to 25 feet below the Big Coal, and is in places rich and persistent. At Oliphant's furnace, seven miles northeast of the Anna, the ore "is fine grained, compact, rich nodular or plate carbonate of iron, from 5 to 6 inches thick, within a few feet of the bottom of the Big Coal, and is known as the *Oliphant ore.* Fifteen feet below the coal is the *Collins ore,* consisting of nodules of heavy blue ore forming 3 to 5 courses with total thickness of 9 to 12 inches, and is a carbonate of iron.

Rogers, in his Geological Survey report for 1839,[6] gave a number of analyses of the iron ores used at these old furnaces in Monongalia and Preston counties which represent the character of the ores partially described in the above paragraphs from his report. The analyses were based on a quantity of 25 grains and are here given on a basis of 100.

Greenville Furnace Ores (Rogers).

	I.	II.	III.	IV.
Iron carbonate	93.08	64.32	60.60	71.16
Lime carbonate	Trace	Trace	Trace	1.40
Magnesium carbonate	Trace	Trace	Trace	.....
Silica	4.48	27.20	31.20	22.48
Alumina	0.80	4.16	3.76	2.96
Water	1.24	1.20	2.00	1.64
Manganese carbonate	Trace	Trace	Trace	Trace
Metallic iron	44.95	31.06	29.27	34.37

I. A compact ore, reddish brown from upper seam at furnace in shales below the conglomerate.

II. Rock vein, 10 feet below last and 8 to 15 inches thickness.

III. Another sample from Rock vein, gray color, earthy fracture, vegetable remains and mica scales.

IV. Lower vein which is 8 to 10 feet below Rock vein and average thickness 4 inches, dull reddish brown color.

Rogers gives in the 1839 report the following analyses of ore at Henry Clay and Valley furnaces in Monongalia,

[6] Geology of the Virginias, pp. 401-404.

and several ores from Preston county, which are here computed on 100 per cent basis:

	V.	VI.	VII.	VIII.	IX.	X.
Iron carbonate	89.12	76.72	78.20	92.00	82.56	66.68
Lime carbonate	.....	3.72	4.40	.....	2.24	0.60
	0.80	.....	.....	1.20	.....	.....
Magnesium carbonate	.....	2.80	3.00	.....	3.76	0.76
Silica	7.48	12.72	11.20	4.08	8.44	24.96
Alumina	1.40	2.04	1.40	1.20	2.12	3.88
Water	0.88	1.76	2.00	1.12	1.04	2.64
Manganese carbonate	Trace	Trace	Trace	Trace	.....	Trace
Metallic iron	43.04	37.05	37.77	44.43	39.87	46.67

V. Ore from upper vein below conglomerate at Henry Clay furnace, gray ore with reddish brown tint, compact texture and fine grain.

VI. Valley furnace ore, reddish brown color, compact texture, contains vegetable impressions.

VII. Valley furnace, Monongalia county, ore, called by miners kidney ore, bluish gray color.

VIII. Iron ore below conglomerate German settlement, Preston county, bluish gray to brown.

IX. Hollow run, a branch of Muddy creek, Preston county, dark blue ore, compact texture.

X. Iron ore from coal measures, M. Hartman's, Crab Orchard, Preston county, color deep red to brown, compact texture and fine grain.

Preston county, location given, showing only the phosphorus and iron content (pp. 578-580).

REMARKS.	Carbonate Ore.	Location.	Natural Ore. Phosphorus.	Natural Ore. Metallic Iron.	Dried Ore. Phosphorus.	Dried Ore. Metallic Iron.	Phosphorus Ratio.
One foot seam ore in pit (8 to 10 feet below surface)	Martin ore	Johnson mine	0.114	35.55	0.114	35.61	0.321
Piles at mouth of shaft	England ore	Johnson mine	0.158	28.72	0.159	28.85	0.550
Piles fresh ore at mouth of drift	Spring Hill ore	Wadsworth mine	0.159	30.35	0.159	30.39	0.524
One lump ore near old mine	Haines ore	Laurel Iron Works on Coles Run	0.148	32.14	0.148	32.20	0.460
Seam ore in drift 50 feet down	Big Honeycomb mine	Hope mine	0.271	30.90	0.272	30.97	0.877
One lump near old workings	Stratford ore	Coles Run	0.154	28.89	0.154	29.95	0.515
Three or four lumps near old workings	Hastings ore	Ice Ferry	0.780	31.13	0.781	31.22	2.506

The phosphorus ratio of ore represents the amount of phosphorus in 100 parts of metallic iron. Thus the Johnson mine ore with 35.55 per cent metallic iron and 0.114 per cent phosphorus would contain in 100 per cent metallic iron:

35.55% iron in ore: 100% iron:: 0.114% phosphorous in ore: x % phosphorous in 100 parts iron, or

$$\frac{35.55}{100} = \frac{0.114}{x}, \text{ or } x = \frac{11.40}{35.55} = 0.321.$$

For Bessemer steel this ratio should be less than 0.1 per cent, so that all of these ores are non-Bessemer.

The U. S. Census report of 1880 gives the following data on Preston county iron industry:

Number of plants............	3
Maximum annual capacity...	75,500 short tons
Iron ore production 1880......	33,825 short tons (carbonate).
Value of plants, 1880	$44,722
Number employes, 1880	130
Cost explosives used, 1880.....	$ 917
Value of plants................	6,500
Value real estate.............	38,000
Total investment.............	49,500

The ore used at the Gladesville and Irondale furnaces is 155 feet above the Upper Freeport coal and is named the Irondale Limestone and Ore by Dr. I. C. White, who gives the following description of it in volume II of the State Geological Survey, (p. 272):

"Near Albright's bridge, Anderson and other points in Preston county, a bed of ferruginous limestone immediately underlies the Bakerstown coal. At Gladesville and Irondale, in the same county, a limestone 4 to 5 feet thick overlies ½ to 2 feet of siliceous limy iron ore, and although no coal is to be seen immediately above the limestone, it is quite probable that it represents the limestone frequently found just under the Bakerstown coal, since its geological horizon appears to be not far from that level. The limestone is of fair quality but not of marine origin, and was used as a flux at the Iron-

dale furnace. The iron ore is a carbonate but rather lean, having only 35 per cent of metallic iron, and 12 to 15 per cent of siliceous matter. It was mined by stripping at Gladesville and at Irondale by both stripping and drifting, the limestone above being taken out for flux, and thus making room to get the ore. The latter was roasted before mixing with 'Lake' ores for use in the furnaces. The ore is too lean for successful iron manufacture, and the furnace has been out of blast for twenty years (1903)."

The following analyses of Monongalia county ores were made in 1876 for the State Board of Managers for the 1876 Centennial by C. E. Dwight, of Wheeling, and published in their report entitled Resources of West Virginia, by M. F. Maury (p. 255). The England, Stratford, Swisher, Haines, and Scott ores were used at the old Deckers Creek furnace, while the Hastings ore was used at Cheat River furnaces. Mr. Maury remarks that the thickness given for these veins is somewhat exceptional and is probably local. He also quotes J. J. Stevenson as reporting the Clippart seam to be the most extensive ore deposit in the county and its horizon in the shale immediately underlying the Pittsburg coal. "It is a proto-carbonate of iron, rich and pure, in some places locally known as the Olyphant blue lump." It was worked by Olyphant near Uniontown, Pennsylvania, for use in the Fairchance furnace.

Analyses of Monongalia—Preston County Iron Ore (Dwight).

	Martin Seam 18 inches.	England Ore 18 inches.	Stratford Ore 18 inches.	Spring Hill Ore 30 inches.	Swisher Ore.	Haines Ore 2 feet.	Scott Ore 18 inches.	Hastings Ore 18 inches.	Clippart Vein 2 feet.	Tunnelton, in Preston Co. Two feet thick. Analysis by Worth.
Carbonate of iron	61.01	69.61	31.19	.....	59.69	.....	49.81	51.67	62.60	67.36
Sesqui oxide of iron	3.44	1.79	11.89	70.49	18.76	57.71	23.80	7.55	2.54	.....
Protoxide of iron	.....	......	.....	0.71	.....	1.22	.....	.....	.....	.....
Oxide of manganese	0.01	Trace	Trace	1.07	1.41	3.34	2.43	0.23	0.02	0.51
Carbonate of lime	11.95	4.91	26.05	2.28	5.22	5.60	13.25	19.26	8.37	18.89
Carbonate of magnesium	2.10	0.21	2.45	1.01	0.31	2.10	3.11	1.35	0.31	6.41
Silica	15.14	20.75	15.55	14.41	13.14	18.19	4.06	15.98	21.62	2.64
Alumina	4.48	1.23	2.12	2.10	0.31	2.10	1.48	1.25	3.21	0.31
Phosphoric acid	0.53	0.71	0.89	0.44	0.37	1.99	0.63	0.69	0.41	*3.32
Sulphuric acid	0.37	0.30	0.42	0.32	0.49	0.74	0.54	0.82	0.22	**0.56
Moisture	0.64	0.48	1.02	6.90	0.38	6.80	0.68	0.76	0.48	.....
Total	99.69	100.00	99.59	99.69	99.97	99.80	99.80	99.56	99.78	.....
Metallic iron	31.86	34.69	27.24	49.69	41.94	41.35	40.71	30.24	32.00	32.52
Phosphorus	0.23	0.31	0.39	0.19	0.16	0.87	0.27	0.30	0.18	0.66
Sulphur	0.15	0.12	0.17	0.13	0.20	0.30	0.22	0.33	0.09	0.13

*Lime phosphate. **Lime sulphate.

TAYLOR, MARION, BRAXTON AND CLAY COUNTIES.[7]

In Taylor county, on Valley river at the mouth of Lost run, an old furnace was located 75 or 80 years ago using a local ore. In the northeastern part of the county next to Preston, a company from Lancaster county, Pennsylvania, erected a furnace named the Lancaster, which worked a local ore. The property was later sold, and in 1876 was owned by the Lancaster Furnace and Mining Co., which built new buildings and furnaces.

In the U. S. Census report for 1880, the following data are given on this property:

Maximum annual capacity	28,000 short tons.
Iron ore mined, 1880	13,798 short tons.
Value of ore in 1880	$24,640
Number employes	65
Value of plant	$ 2,000
Value real estate	6,000
Total capital invested	10,000

Mr. Maury, in report quoted (p. 257), states that "two miles from the mouth of Lost Run, on the steep hill in front of John Riley's house are three strata, each 8 inches thick, of an excellent carbonate of iron, imbedded in 8 feet of rotten slate and clay. Below these are nodular pieces of 3 to 15 pounds weight in blue clay." A similar ore is reported from Plummer's Run. Maury gives the following analyses (p.258) of the carbonate iron ores at Riley's, and at the two old furnaces, made by C. E. Dwight:

One of these old furnaces was located eight miles east of Fairmont, on the Tygart Valley river, and was on the line of the Baltimore and Ohio railroad, so was torn down when this road was built.

7 Data mostly from Maury, Resources of West Virginia; 1876.

	Lancaster Furnace.	Mouth of Lost Run.	Near Riley's House.
Iron carbonate	31.34	24.576	33.141
Iron peroxide	33.98	34.443	33.100
Manganese binoxide	.....	Trace	0.256
Lime carbonate	16.52	13.913	12.495
Magnesia carbonate	5.28	3.478	3.214
Sulphuric acid	0.13	1.201	1.050
Phosphoric acid	0.68	0.477	0.536
Silica	9.36	16.260	7.536
Alumina	1.31	2.982	4.978
Water and loss	1.40	2.673	3.697
	100.00	100.000	100.000
Metallic iron	38.91	35.983	39.100
Phosphorus	0.296	0.207	0.234
Sulphur	0.052	0.480	0.420

Lesley describes an old furnace located five miles east of Fairmont known as the Piney, a cold blast charcoal furnace, 32 feet high with 8½-foot bosh, which made in 37 weeks of 1856, 800 tons of metal from the coal measure ore cropping from one-half mile north and south. It was abandoned in 1856. Six miles from Fairmont, Squire Bruce owned in 1879 the West Fork furnace, stated by Lesley to be in good order, but not run since 1839.

Near Clarksburg, in Harrison county, Judge Jackson operated the number 1 furnace one mile east of town. It was abandoned in 1847. Number 2 furnace, one mile west of Clarksburg, owned by the late Col. Ben Wilson, was torn down in 1846 (Lesley, 1859).

In Braxton and Clay counties, Mr. Maury gives the following observations on iron ores made by him in 1874 (pp. 258-260):

"In 1874 the Elk River Iron and Coal Co. built a furnace at the mouth of Strange Creek, in Braxton, close to the Clay line, and since that date have gone into operation, making a No. 1 cold blast charcoal iron. Their developments have shown some most excellent beds of ore.

"In Clay county, at the mouth of Standing Rock Run, 246 feet (barometer) above Elk river, is a fine deposit of nodular brown oxide of iron, the result of decomposition

from the carbonate. The nodules are very thickly imbedded in a soft gray clay, and will yield from 35 to 40 per cent of metallic iron, and being soft and cellular, work well in the furnace. The bed averaged 4 feet thick, but when examined, there was no roof exposed, and the ore was still under foot.

"Mr. J. Savage, the president of the company, who made this opening, said that at one place he went to the bottom of the bed, and found the total thickness 6 to 7 feet. He also traced the seam for 3½ miles by walking along the outcrop, and striking his pick in at every 80 or 100 yards, till he rolled out nodules of the ore, and having noted it in the same way at many other places, feels confident that it runs for many miles up and down Elk river. About 15 feet lower down the hill was a very encouraging outcrop, which, however, was not sufficiently opened to speak of its thickness.

"About a mile higher up the river, and below the last, is another seam of the same class of ore, though not quite so rich. It was opened enough to prove the existence of a workable bed, but the exact thickness could not be measured. Just across the river it is partially opened again. Here the ore is of better quality, and in very valuable and easily workable quantities. Above this, on the east side of the river, Mr. Savage opened a 2½-foot bank.

"These three seams are found again from 2 to 4 miles below the company's furnace in Braxton county. Concerning the mineral at these points, Mr. Savage, under date of March 22d, 1876, writes: 'Our heaviest seam of ore, which is of a grayish color before it is burnt, lies 50 feet above Elk river and is a regular bed. We also have two more regular beds which are 100 and 150 feet respectively, above the stream. There is another seam in which the ore lies in pockets or bunches, sometimes 3 or 4 feet thick, and again running out completely. Near the top of the hill is what is called *the top hill ore,* which is scattered promiscuously over the country, and appears to be more plentiful in Clay than in Braxton county. * * *

'The furnace of this company is 42 feet high and 11 feet across the boshes. Concerning its working, the same gentle-

man mentioned before has kindly furnished the following points: 'We are making only about 8 tons per day at this time (March 22, 1876) using 18 tons and 580 pounds of roasted ore, 4 tons and 600 pounds limestone and 1,500 bushels of charcoal. These cost us:

Charcoal......	5 cents per bushel delivered.
Limestone	$2.00 per ton.
Ore	2.25 " "

'Expenses of manufacturing about $21 per day. These items give a cost for the pig iron of about $17 per ton. In good weather on dry stock we can make an average of 10 to 11 tons a day, which will make the pig cheaper. The reasson that we are not making more now is because last season was a very bad year to make charcoal, and it was out in the weather and is in bad condition, as we had not gotten up our coal house. The in-wall bosh and hearth rock were obtained from this neighborhood and are superior to fire brick.' The ore beds of this region occur in the lower barren group of the coal measures (Conemaugh Series)."

This furnace was a failure, and never made any commercial iron, as the ore was too low.

The following data on this furnace are given in the U. S. Census report for 1880:

Maximum annual capacity.............	5,000 short tons.
Iron ore production in 1880............	2,500 short tons.
Value of ore in 1880..................	$3,333
Number of employes in 1880...........	10
Value of real estate..................	$4,500
Value of plant........................	500
Total capital invested................	5,350

WAYNE, KANAWHA, RELEIGH COUNTIES.

Black band iron ore is reported from Wayne county, near the Big Sandy River, and the following analysis is given in the Maury report of 1876 (p. 249)of the same ore, 2½ feet thick just over the state line in Kentucky:

	Per cent.
Iron protoxide	34.07
Iron peroxide	2.31
Alumina	0.43
Silica	3.34
Lime oxide	7.31
Magnesia oxide	6.30
Carbonic acid	37.40
Phosphoric acid	0.17
Sulphur	0.34
Organic matter	6.45
Water	2.30
	100.00
Metallic iron	28.12 per cent.

Mr. Dwight, in the Maury report of 1876 (p. 261), made the following section at Cassville on Big Sandy river in Wayne county to show the relation of the different beds of iron ores:

	Top of the Hill.	Feet.
	Interval	60
10.	Clay with kidneys red hematite (58 per cent iron)	3
	Interval	138
9.	Limestone ore	1
	Interval	14
8.	Clay and kidneys of iron ore	3
7.	Carbonate of iron and limestone	2
	Interval	37
6.	Clay with kidneys of red hematite (55 per cent iron)	......
5.	Mixed stratum of limestone and iron ore (latter 42 per cent iron)	2½
	Interval	52
4.	Black manganiferous iron ore (25 per cent manganese oxide) (27 per cent iron)	2½
	Interval	12
3.	Carbonate of iron	2
	Interval	104
2.	Shale with lumps blue carbonate iron (34 per cent iron)	5
	Interval	8 to 10
1.	Clay and fossiliferous iron in kidneys	5
	Interval	155
	Level of Big Sandy river.	

"Nos. 5 and 6 are known as the Wilson Seam and an analysis of the mixture of the ores therefrom shows:

Peroxide of iron	16.20
Protoxide of iron	25.70
Protoxide of manganese	20.85
Caustic lime	30.22
Silica	3.56
Alumina	3.11
Phosphoric acid	0.64
Sulphur	Trace
	100.00

"In December, 1875, 58 tons of this ore were tried at the Belmont furnace, Wheeling, and so much liked that an order for 1,000 tons was at once given."

The black manganiferous ore, No. 4, above, has the following composition, according to C. E. Dwight (Maury report, p. 262):

Sesquioxide of iron	27.400	
Binoxide of manganese	26.802	
Carbonate of lime	37.214	
Carbonate of magnesia	1.908	
Silica	1.866	
Alumina	1.000	
Phosphoric acid	1.557	
Sulphuric acid	0.354	
Moisture	1.770	
Loss	1.029	
	100.000	
Metallic iron in raw state	19.18	per cent.
Metallic iron in roasted ore	27.87	" "
Phosphorus	0.679	" "
Sulphur	0.142	" "

In Kanawha county, Maury (p. 249) states that many openings have been made on the black band iron ore on Davis and Briar Creeks, where the seam is 6 to 7 feet thick with 4 to 5 feet of good workable ore.* Maury gives the following analysis of this ore as made by Otto Wuth, of Pittsburg, in 1876:

Carbonate of iron	68.35	
Silica	4.64	
Phosphoric acid	0.58	
Sulphur	0.42	
Carbonaceous matter (some lime and alumina)	26.02	
	100.00	
Metallic iron	33	per cent.

Mr. Wuth comments on the analysis as follows: "Thoroughly roasted, it would then contain about 65 per cent of metallic iron, while there is more than enough carbonaceous matter to roast it. I consider it a black band ore of the first quality."

The following analyses of Kanawha county iron ores were made by Prof. W. B. Rogers and given in his geological report for 1840,[8] and one analysis of Nicholas county ores is included:

	I.	II.	III.	IV.
Carbonate of iron	82.55	.....	.....	.....
Peroxide of iron	.....	58.41	83.00	80.75
Alumina	1.00	3.45	5.45	1.25
Silica and insoluble	12.05	32.44	10.90	7.40
Oxide of manganese	.....	.....	0.25	.....
Water	3.50	4.50	.....	10.00
Loss	0.90	0.20	0.40	0.60
Metallic iron	39.85	40.88	58.10	56.52

I. Iron ore from Kelley's Creek, Kanawha county, in shales. A nodular iron ore with nodular structure, compact, close grained, color dull reddish gray.

II. Iron ore in the red shales above the blue sandstone at Red House shoals in Kanawha county. Compact structure somewhat slaty, close grained; color crimson brown without luster.

III. Iron ore on the dividing ridge betwen Eighteen Mile Creek and Kanawha river, in Kanawha county, one mile from river back of Mr. Hervey's. Structure massive, close grained; color dull brown with glimmering micaceous points.

IV. Iron ore on Hamilton place, Nicholas county, on top of hill in rounded masses. Structure irregularly nodular, texture brittle; color chestnut brown with blackish spots of a dull resinous luster.

Mr. Maury gives the following account of the iron ores in Kanawha county in 1876 (pp. 260,261):

"As far as examinations have gone, only the northwestern half of this county can lay claim to iron ore. Those exposures that have been observed are: A 2-foot bed in the hills across Elk river, opposite Charleston, from which the Kanawha Iron Company, whose furnace is now building,

*The furnace erected five miles below Charleston to operate on this ore was a total failure, as ore was too low.—I. C. W.

8 The Geology of the Virginias, pp. 531, 532.

expects to draw a portion of its supplies; a bed 2 feet 2 inches thick, one and a quarter miles up Campbell's Creek, of a brown oxide, lying just above the Black Flint ledge. It has, however, a good deal of sand in it, and would have to be mixed with other and richer ores for furnace use.

"A seam on the Davis creek side of the dividing ridge between that stream and Rush Creek, was opened some 15 or 20 years ago (1855 or 1860) with the intention of starting a small furnace, but the idea was abandoned. It is 2½ feet thick, according to the recollection of General L. Ruffner, and is on the Black Flint. It is therefore, the same bed as the last. The ore that is still lying about is a siliceous brown oxide, containing some 30 or 40 per cent of iron. It would mix well with the richer ores of Virginia.

"Lower down Davis Creek several workable seams of carbonate of iron, or the results of its decomposition, are reported an analysis by O. N. Stoddard, of one 80 feet above the Mahoning sandstone showing:

Iron	34.927
Carbonate of lime	9.400
Carbonate of magnesia	2.450
Siliceous matter	15.400
Alumina	4.210
Manganese	2.900
Sulphur	0.243
Loss of water by drying	0.400
Loss on ignition	27.800
Loss	2.270
Metallic iron in the roasted ore	48.6 per cent.

In Raleigh county, Maury, in 1876, (p. 263) gives an analysis by C. .E Dwight of a brown hematite, earthy and porous in texture from a bed 3 feet thick found on the Wm. McCreery farm, 3 miles north of the Court House.

Peroxide of iron	79.350
Silica	3.599
Alumina	1.593
Phosphoric acid	1.880
Sulphuric acid	0.895
Lime	0.821
Manganese	0.034
Water	11.232
Organic matter and loss	0.589
	99.993
Metallic iron	55.545
Phosphorus	0.819
Sulphur	0.358

MONROE GREENBRIER, POCAHONTAS COUNTIES.

Mr. Maury (1876) quotes a report of C. R. Boyd on iron ore in Monroe county as follows: "Little Mountain, lying next to Peters Mountain, on the south boundary possesses a very fine deposit of iron, from which metal of good quality has been manufactured." Maury also states (1876) that "on Peters mountain on the road from Union to the Salt Pond, a very fine outcrop of brown hematite has been observed and along the eastern border of the county it is probable that other deposits will be found." Near Crimson Springs are the ruins of an old furnace, said to have been abandoned 60 to 75 years ago, but the old openings are still quite distinct.

The iron ores in Greenbrier county, as known in 1876, are described by Maury (p. 265)as follows: "On Howard's Creek, within 4 or 5 miles of the White Sulphur Springs, iron ore of fair quality and apparently in large quantities has lately been discovered; and on Anthony's Creek the fossiliferous and block ores make their appearance. At the point of observation the fossil ore was 9 inches thick, but the block ore has been opened at two places, each showing 7 feet. It inclines at a good angle for mining. A bluff ore also shows itself at numerous points in large masses (Report of T. S. Ridgeway)." Analyses are given by Maury as made by J. B. Britton:

Fossil ore	52.23	per cent iron.
Pipe ore	61.75	" " "
Hematite ore	57.17	" " "
Blue ore	56.69	" " "

In Pocahontas county, Maury, in 1876, writes that large bodies of iron ore are supposed to be present in the county, but there were no data as to quality of the ore or thickness of the deposits.

HAMPSHIRE AND MORGAN COUNTIES.

In Hampshire county, 12 miles south of Romney, was located an iron furnace known as the Hampshire Furnace, which, according to Maxwell and Swisher,[10] was built by Edward McCarty somewhere near 1800. Old county records show a prosperous business at this furnace in 1816 and 1817, but no later account has been found, and the furnace was torn down many years ago.

According to the history above quoted, the Bloomery Furnace, in the eastern part of the county, was built in 1833 by a Mr. Pastly and a few years later was owned by Passmoor, who placed a man named Cornwell in charge. He operated the furnace until 1846, and transported the iron on rafts and flat boats down the Cacapon river.

S. A. Pancost bought the property in 1846 and operated it to his death, in 1857. It was then operated by his heirs under the name of Pancost and McGee. John Withers was superintendent until 1875, when the furnace was closed down. It was operated for a short time in 1880 and 1881. The U. S. Census report for 1880 gives the following data on this property:

Maximum annual capacity	8,500	short tons.
Iron ore production in 1880	7,000	short tons (fossil ore.)
Value of ore in 1880	$10,500	
Number of employes in 1880	25	
Value of plant	$ 6,000	
Value real estate	10,000	
Capital invested	17,000	

10. History of Hampshire county, p. 533; 1897.

Plate II.—Lower Helderberg Limestone Cliffs, near Franklin, Pendleton County.

The same report gives the following analyses by Whitfield of the ores used at the Bloomery Furnace:

Natural Ore.		Dried Ore.		Phosphorus. Ratio.
Phosphorus.	Metallic Iron.	Phosphorus.	Metallic Iron.	
I 0.086	38.04	0.087	38.40	0.226
II 0.286	49.53	0.294	50.94	0.577
III 0.996	47.05	1.011	47.78	2.117

I. Across breast, ore 12 feet thick, avoiding interbedded clay at furnace. Limonite.

II. From 500 tons at furnace, brought from northeast of furnace. Fossil.

III. From 100 tons at furnace brought from southwest of furnace. Fossil. Titanium present.

Maury (p. 271) in 1876 quotes Guerard as follows on this property: "Here a fossiliferous variety of brown hematite occurs in a vein, varying from 18 inches to 4 feet. This and a vein of the ordinary brown iron ore (thickness not known) have been mined and smelted here for many years. The furnace has been out of blast for the last few months, but will probably soon be in operation again. Limestone, charcoal and fine water power are easily obtained anywhere along this valley. The following are the general proportions of the charge and the production of the furnace, as given me by Mr. Withers, the present manager and part owner:

$$\text{Cold blast}\left\{\begin{array}{l}\text{800 pounds limestone}\\ \text{120 bushels charcoal}\\ \text{2½ to 2¾ tons raw ore.}\end{array}\right\}\text{ to 1 ton pig iron.}$$

"Cost $20.00 per ton pig delivered at Pawpaw station, distant 14 miles."

Mr. Maury (p. 272) gives the following analyses made by Dwight in 1875 of two brown hematite ores from Short mountain, 15 miles south of Romney.

	Per Cent.	Per Cent.
Sesquioxide of iron	73.531	75.250
Binoxide of manganese	4.380	Trace
Silica	13.329	12.035
Alumina	3.025	2.199
Lime	0.024	1.254
Magnesia	0.251	0.631
Phosphoric acid	0.241	0.089
Sulphuric acid	1.204	2.058
Combined water	3.082	0.750
Hygroscopic water	0.632	0.631
Loss	0.301	0.524
	100.000	100.000
Iron	51.471	52.675
Phosphorus	0.105	0.038
Sulphur	0.481	0.823

The McCarty charcoal furnace near Paddington railroad station in Hampshire county is described by Lesley as standing in 1856 but abandoned 30 years before.

Mr. Maury quotes Guerard in 1876 (p. 272) on the ores of Morgan County as follows: "There are no iron ores of any importance in this county. On the slopes of Sandy ridge, near Sir John's Run station, are two veins of ore of a siliceous character, one measuring 6 and the other 2 feet, but not workable, except under peculiar circumstances.

"At various points along the summit of Sleepy Creek mountains boulders of ore may be observed, but indicating no workable deposits. It may be mentioned more as a mineralogical curiosity than as of economical importance, that specimens of micaceous hematite may be picked up frequently in both this and Berkeley county, at the base of the mountain."

No mention is made in this report of 1876 of any iron furnace in the county, but the U. S. Census report for 1880, states there is one furnace at that time in operation, and gives the following data on its work:

Maximum annual capacity..........	16,800 short tons.
Iron ore production in 1880........	2,800 short tons limonite.
Value of ore in 1880................	$ 5,000
Number of employes................	30
Value of plant in 1880...............	$ 1,500
Value of real estate in 1880........	5,000
Total capital invested..............	8,000
Cost of explosives in 1880..........	84

GRANT, PENDLETON AND HARDY COUNTIES.

The iron ores of Grant county are described in 1876 as follows by Guerard in the Maury report (p. 269): "In the vicinity of Greenland Gap, the red fossiliferous hematite shows itself in 5 parallel layers, on the east side of Walker's ridge, dipping northwest, and on the west side of Little or Knobly mountain, dipping southeast, indicating the wreck of a denuded anticlinal arch over the New Creek mountain. These seams, workable in Pennsylvania when only a few inches thick, here assume the following large dimensions:

(a).........	8	feet	Walker's Ridge (measured from outcrops.)
(b).........	18	"	
(c).........	13	"	
(d).........	11	"	
(e).........	7	"	..Little Mountain (measured from section.)
	—		
	57		

"On either side and overlying these strata, massive beds of limestone (partly hydraulic) and sandstone are exposed. Above the latter the brown hematites crop out along the summits of Walker's ridge and Knobly mountain. On these ores the Fanny Furnace, 4 miles from the village of Greenland, on Hasard's Creek, formerly worked, being long famous for its iron."

At present time a small portion of the furnace stack remains, with large slag piles below. The furnace has probably been abandoned 60 years or more, and was partially destroyed to furnish stone for building foundations. Its location is on the Babb farm to east of county road, and a mile northeast of entrance to Greenland Gap. The creek was widened into a large pond by a dam to furnish water

power for the furnace. A number of stoves are found in this county which were made at the Fanny Furnace and its reputation for a high grade of iron was well established through all the surrounding counties. While part of the ore came from limonite boulders scattered over the mountain sides, a large portion came from the fossil hematite veins on the Lewis farm about the center of Greenland Gap. It was here worked by benching and stripping along the side of a low ridge and worked over a length of about one mile, but at present time the ore is concealed by debris.

Mr. Maury gives in 1876 two analyses of the red hematite from near Greenland Gap on Little Mountain, the 7-foot seam (No. 1), and a similar variety from a 13-foot seam on Walker's Ridge in the same neighborhood (No. 2). Both analyses were made by C. E. Dwight, and he says that the 13.733 per cent referred to alumina in anaysis No. 2, includes also the moisture and loss.

	No. 1.	No. 2.
Sesquioxide of iron	75.033	68.750
Binoxide of manganese	0.025	....
Silica	14.354	15.555
Alumina	7.445	13.733
Magnesia	0.230	....
Lime	0.521	....
Phosphoric acid	2.020	1.842
Sulphuric acid	0.240	0.120
Loss, etc	0.132	....
	100.000	100.000
Iron	52.52	48.130
Phosphorus	0.880	0.803
Sulphur	0.096	0.048

The following analyses of the fossil ore at Lewis farm mines, and from Wm. Michael farm on Walker's ridge are given in U. S. Census report of 1880:

Natural Ore.		Dried Ore.		
Phosphorus.	Metallic Iron.	Phosphorus.	Metallic Iron.	Phosphorus Ratio.
I. 0.554	43.09	0.559	43.50	1.286
II. 0.487	47.36	0.487	47.36	1.028

I. Across two beds, ore aggregate thickness 20 inches. Lewis farm.

II. Across three beds, ore aggregate thickness 6 inches. Michael farm.

Mr. Guerard, in 1876, writes as follows on the iron ores of Pendleton county in the Maury report (pp. 266, 267):

"The principal deposits of this county are in the eastern portion, along the South Fork mountain, a few indications only of no special importance being observed on the ranges of the North Fork. * * * The red fossiliferous hematite, the most uniform and important of this group, displays itself at many points along the sides and summit of the South Fork range. This ore, from its occurrence in layers arranged parallel with each other, interstratified with friable red shales, and from its being usually filled with impressions of hollow castings of shells, admits of being readily identified and is traceable in a series of seams, though seldom very thick, in considerable numbers, and for a great distance; it presents everywhere the same natural advantages, indicating the abundance in which it might be procured, as well as the facility with which it might be mined.

"Of its extraordinary value to any region, the experience in Pennsylvania furnishes the most conclusive evidence, where since the discovery of its admirable adaption for the furnace, it has been keenly sought after, and seams which, from their thickness, would, if composed of any other material, have remained unnoticed, have not only been diligently but profitably worked. This formation, which further north

and south is not so well developed, expands in passing through this state, and here attains a thickness not found elsewhere.

"Associated with these strata, at the junction of this with the overlying formation, are found valuable deposits of red and brown hematites derived probably from the former. These appear in outcrops and scattered boulders along the entire length of this mountain."

The following analyses made of the Pendleton county ores in 1875 by Dwight are given in the Maury report (p. 276):

	I.	II.	III.	IV.	V.	VI.
Sesquioxide of iron	63.470	80.336	80.838	50.010	70.201	55.706
Binoxide of manganese	3.150	....	Trace	....	Trace	....
Silica	18.000	5.722	17.544	37.151	17.361	18.110
Alumina	5.707	7.291	1.266	8.390	3.503	13.463
Lime	0.146	1.517	Trace	0.756	0.456	1.321
Magnesia	0.713	0.482	Trace	0.432	1.489	0.120
Phosphoric acid	0.300	1.331	0.026	0.080	2.400	0.090
Sulphuric acid	1.575	1.070	0.423	0.925	1.345	2.147
Combined water		6.197		1.877	2.754	7.799
Hygroscopic water	0.432	....	....	....	....	0.732
	....	1.864	1.020	....	....	....
Loss	0.310	....	....	0.379	....	0.512
	100.000	100.000	100.199	100.000	100.000	100.199
Iron	44.42	56.232	56.586	35.010	49.137	38.994
Phosphorus	0.131	0.580	0.012	0.035	1.046	0.039
Sulphur	0.730	0.428	0.169	0.370	0.538	0.858

I. Brown hematite from near Franklin.
II. Red fossil hematite from Dickinson land on South Fork mountain.
III. Red hematite from vicinity of Upper Tract.
IV. Red and brown hematite (mined) from George Miller's South Fork mountain.
V. Red hematite (part of No. IV).
VI. Brown hematite from Col. Johnson's place, near Franklin.

Mr. Guerard also reported on the iron ores in Hardy county in 1875—6 given in the Maury report (pp. 267, 268):

"On the west side of Elk Horn Knob, 13 miles south

from Moorefield, three separate seams of the red fossiliferous hematite crop out with the usual favorable characteristics of this valuable formation. They measure respectively:

(1)	0 feet,	8 inches		
(2)	1 "	6 "		Ketterman's farm.
(3)	3 "	3 "		

"The upper ores of this group are remarkably well shown on the same range:

(1) Red hematite, 25 feet (16 feet solid ore)—Pine mountain, 1½ miles from Ketterman's.

(2) Brown hematite, 30 feet (from outcrop)—Salt Spring Run Knob, 5 miles from Ketterman's.

(3) Brown hematite (very pure), 14 feet—Cunningham's tract, 3 miles from this and 9 from Moorefield.

"The brown hematites occur largely again on the spurs and ridges of the North or Capon mountain. These have long been mined and smelted by various iron works in this portion of the county. The only furnace now in existence (1876), is that known as the Capon Iron Works, six miles from Wardensville on the east side of the mountain.

"The following data show the general charge and working of the Capon furnace:

Cold blast at ⅝ pounds pressure.	800 to 1,000 pounds limestone	to 1 ton pig iron.
	140 to 160 bushels charcoal	
	2 to 3 tons charred ore	

25 to 30 tons pig iron a week.

Cost $15 per ton at works.

Shipping point Winchester, distance 20 miles.

"The ores worked are said to produce an excellent quality of iron, especially adapted to the manufacture of car wheels and boiler plate.

"Of the furnaces formerly worked, but now abandoned, there were three in this county: One on Orr's mountain, west of Moorefield and two on the east side of the mountain. In the neighborhood of Wardensville Messrs. Saliard and

Bryan carried on a furnace many years ago, and 8 miles from Capon Iron Works, on the same range, was the Crack Whip Furnace, owned by Charles Carter Lee. A large deposit of ore was developed in this locality, as shown by the old workings still exposing several feet of solid ore." Bryan's charcoal furnace, on the Hezekiah Clegget farm, was abandoned in 1840.

Maury gives the following analyses of Hardy county ores, as made by C. E. Dwight

	I.	II.	III.	IV.
Sesquioxide of iron	84.800	72.990	83.470	64.287
Protoxide of iron	....	....	4.640	....
Binoxide of manganese	....	....	Trace	7.680
Silica	5.900	23.500	9.400	11.771
Alumina	......	......	1.810	3.184
Lime	....	....	....	2.657
Magnesia	....	....	....	1.141
Phosphoric acid	1.600	0.122	0.373	1.110
Sulphuric acid	0.100	0.870	0.120	1.180
Water	....	....	....	6.695
Water and Loss	4.600	2.518	0.187	....
Loss	....	....	....	0.295
	100.000	100.000	100.000	100.000
Iron	59.360	51.090	62.010	45.000
Phosphorus	0.698	0.053	0.163	0.483
Sulphur	0.040	0.035	0.048	0.472

I. Red fossil hematite from 3 feet, 3-inch seam on Ketterman farm.
II. Red hematite from 25-foot vein on Pine mountain.
III. Brown hematite from 14-foot vein in Cunningham tract.
IV. Brown hematite (Half Moon mine) from Capon Iron Works.

The old Capon Furnace, six miles south of Wardensville, is still standing in fair condition of preservation. It had a capacity of 4 tons and was built before April, 1832, for in that year is recorded the reorganization of the Capon Furnace Company, by the formation of the firm of James Sterrett & Brother (Alexander M.). It was built by the former, according to Lesley, in 1822, and the value placed on the property at this time, in 1832, was $15,000. James Sterrett died in 1834, and the furnace was operated to Aug. 12, 1835, by the administrator of his estate. The old book account gives no record from 1835 to 1856, but in the latter year the property

was sold to J. J. Keller and was then known as Capon Iron Works. It continued in operation until 1875, when it was shut down. The accumulated ore on the dump was worked up by a short run in 1880 and then the plant was permanently abandoned. It cost $10 a ton to transport the pig iron across the mountain to the railroad, which made a total cost of $25 a ton for the iron at the railroad. The average price of the iron during the successful career of the furnace was $40 to $60 a ton, but after price declined to $25 and $30 the work proved a failure.

A forge was built near the furnace near the end of its active history, but yielded little profit.

Lesley, in 1866, states the forge was equipped with two hammers driven by water power, four fires; and made in 1855, 220 tons of blooms and bars. The furnace was 30 feet high, 9 foot bosh. An old circular bill of sale of the company lists the equipment as follows:

One horizontal stationary steam engine, common slide. or D valve, 11-inch bore and 30-inch stroke, rated 30 horse power.

One set blowing cylinders (two cylinders) bore 37-inch, stroke 38-inch, all connections and gearings complete.

Lot of hand and standing ladles, part of cupola outfit.

One steam hammer, 9-inch bore, 34-inch stroke or drop for bloom.

Two cylindrical boilers (iron)31-inch diameter, 38 feet long.

Two sets forge fire castings and one run-out.

One rock crusher, Blake pattern, 10-inch by 7-inch, complete.

One six-ton track scale used for weighing ore on tramway, complete.

Castings for double ore wash,, paddle pattern, complete.

One 1-ton platform scale for bridge house barrows.

Castings for saw mill carriage and feed gear, complete.

Lots of tools for forge and blacksmith.

One turbine wheel (new) 8 horse power.

Land, 4,100 acres.

Twelve miners 'cabins, one six-room cottage, stables and sheds.

The U. S. Census report for 1880 gives the following data on Capon Furnace:

Maximum annual capacity.........		6,720 short tons
Iron ore production in 1880.........		448 short tons limonite.
Value of production in 1880........	$	400
Number of employes in 1880.........		6
Value of plant in 1880..............	$	150
Value of real estate................		25,000
Capital invested....................		25,150

The Census returns for the state in 1880 are as follows:

Number of furnaces	8
Maximum annual capacity	140,520 short tons
Total production in 1880	60,371 short tons
Total value of ore in 1880	$91,057
Number of employes	266
Total capital invested	$115,550

The Armory Forge was located at Harpers Ferry and owned by the U. S. Government. Lesley states it was built in 1854 with four fires, one hammer operated by water power. It made 50 tons of arms in 1856 (Lesley).

CHAPTER VI.

IRON ORES IN PENDLETON COUNTY.

GEOGRAPHY OF PENDLETON COUNTY.

Pendleton county is one of the mountain counties of the state, located in the extreme eastern part, adjoining the state of Virginia. Its history as a separate county dates from 1787, when it was formed from parts of Augusta, Hardy and Rockingham counties and named in honor of Edmund Pendleton, President of the Virginia Court of Appeals. Its area is 707 square miles,[1] with a population of 9,167. The county seat is at Franklin, which has a population of 205. The mean annual rainfall is 50 to 60 inches, and mean annual temperature 45° to 50°. The main pursuit of the people is agriculture and stock raising, a few small flour or grist mills representing the manufacturing industry. They are a prosperous people who have preserved the open and free courtesy and hospitality characteristic of their Virginia ancestors, so that the word stranger is almost unknown to them.

The county is bounded on the north by Grant and Hardy counties; on the west by Randolph and Pocahontas; on the south by Highland county, Virginia; and on the east at the crest of the Shenandoah Mountain by Rockingham county, Virginia. There is not a mile of railroad in the county, and the nearest railroad points from the county line are: At north, Keyser on Baltimore and Ohio and Western Maryland railroads, 45 miles distant; at east, Broadway or Harrison on the Southern railway, 20 miles; at west, Horton, 4 miles distant, or 20 miles from Franklin, on Dry Fork lumber railroad, which connects with the Western Maryland at Hendricks.

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1 Statistics in this section from U. S. G. S., Bull. 233, Gazetteer of West Virginia.

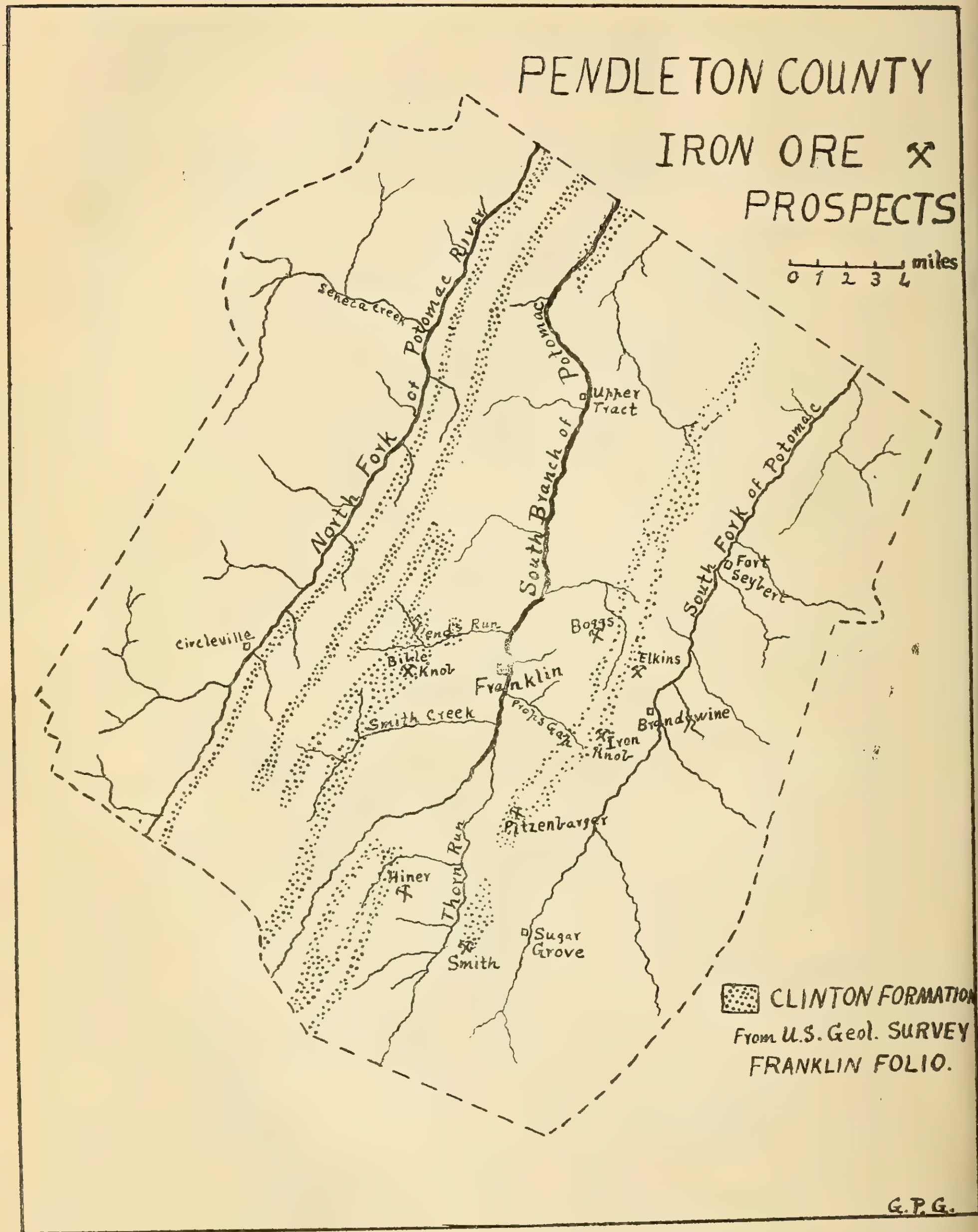

Fig. 4. Sketch map of Pendleton County, Showing Location of Iron Ore Prospects.

Franklin, the county seat, is located in the South Branch river valley near the center of the county. Here are located the court house, general stores, comfortable hotels, and it is a central point to reach the iron ore deposits. The town is 16 miles from north line of the county and same distance from south line. It is 12 miles from the east line and 14 miles from the west line. At the present time it is reached by a daily stage from Harrisonburg, Virginia, 42 miles, and by a daily stage from Keyser, West Virginia, a distance of 68 miles, requiring a two-days journey. By way of these stage lines, Franklin is 237 miles from Pittsburg and 180 miles from Baltimore.

TOPOGRAPHY OF PENDLETON COUNTY.

The county is traversed by northeast-southwest valleys separated by parallel mountain ranges which must be crossed going east or west, but the valleys can be followed by good roads north or south. The mountains are steep and rough, broken into ranges of longer or shorter extent, and are cut by small stream valleys forming numerous gaps, through some of which the county roads pass.

The county is drained by the headwaters of the South Branch of the Potomac, with the main tributaries in parallel valleys. The Allegheny Mountains form the western border, their crest marking the county line, 4,200 to 4,500 feet above the sea level. Spruce Knob. 4.860 fee,t is the highest point in the state. Between this range and the valley are the shorter ridges, Spruce Mountain and Timber Ridge, cut by the transverse gorge of Seneca creek, and which rival in height the main range.

To the east of these mountains is the deeply cut valley of the North Fork of the Potomac, a half mile wide in a few places but usually a narrow gorge. Its level varies from little over 2,000 feet at Circleville to 1,500 feet at north line of the county. In a distance of 13 miles to mouth of Seneca the river has a fall of 40 feet to the mile and from there to north county line, 10 to 12 feet to mile. Its course is nearly straight, being only 4 miles longer than the air line course.

It joins the South Branch in Grant county, 5 miles west of Petersburg. The county road following this river in its narrow valley frequently crosses the river with a number of rough and often dangerous fords.

The central part of the county is marked by the broader valley of the South Branch, separated from the North Fork valley by the North Fork Mountain, 3,000 to 3,500 feet high, and broken on its eastern slope by a number of short ranges, known at the north as Big Mountain, Timber Ridge, and the ridges of the Smoke Hole settlement; at the center Castle Mountain, Buffalo Hills, Pond Ridge, Colic Mountain; at the south, Bobs Mountain, Simmons Mountain. In this southern area the river divides, its eastern branch being known as Thorn run, and the two streams are separated by three short ridges—Jack Mountain, Sandy Ridge, Botkins Ridge. These minor ridges, cut by cross and longitudinal deeply cut valleys, make a very rough country.

The South Branch has its head waters near the south line of the county and flows north, joining the North Branch 18 or 20 miles southeast of Cumberland, Maryland, forming the Potomac. This valley in Pendleton county is 2 to 4 miles wide, with an elevation of 2,400 feet at the south line; 1,750 feet at Franklin, or a fall of 43 feet to the mile; 1,300 feet at north line of the county, a fall of 21 feet to the mile from Franklin. The river course is slightly winding, increasing the distance only 4 miles over a straight line.

This valley is separated from the South Fork valley to the east by the South Fork Mountain, 2,500 to 3,000 feet above sea, which, like the other mountains, is broken into ridges. At the north, Middle Mountain and Cave Mountain come between the main mountain and the South Branch, while further south are Long Ridge, Dickerson and Little Mountain.

To the east of South Fork mountain is the South Fork valley, which has an elevation of 1,900 feet south of Sugar Grove, 1,650 feet at Brandywine and 1,300 feet at the north line of the county. The fall is very uniform, 20 feet to mile throughout the length of the river in the county, which is 28 miles, while the air line distance is 25 miles. The valley aver-

ages 3 miles in width with a very steep slope on the west and more gentle to the east.

The eastern boundary of the county is marked by the Shenandoah Mountain, which has an elevation of 4,000 feet at the south and 3,250 feet at the north, with a few knobs 4,200 feet. The mountain slopes to South Fork 462 feet to the mile at the north and 410 feet to the mile at Brandywine. The crests of these mountain ranges and the river valleys at the south line of the county are almost uniformly 7 miles apart, and at north line, 4 miles apart except the distance from crest South Fork mountain to South Branch, which is 9 miles. These valleys, while mostly narrow, contain broad acres of fertile land. The rivers are usually fordable, but are seldom bridged, so that in certain seasons, travel in and out is practically impossible. Their rapid fall would furnish water power at many places. The tops and even the slopes are cultivaed in many places, and much of the area is covered with forests, though much of the timber has been cut, leaving second and even third growth.

GEOLOGY AND STRUCTURE.

The rocks of the Pendleton county area belong in the Paleozoic epoch. The kinds represented are shales, limestones and sandstones. At the western side of the county, the lower members of the Coal Measures are exposed, with the underlying Lower Carboniferous series, including the Pocono sandstone, Greenbrier limestone and Mauch Chunk shales. The folds of the North Fork mountain expose near the crest the Shenandoah limestone and the Martinsburg shales of the Lower Silurian. The North Fork and South Fork mountains show outcrops of the Upper Silurian and the Oriskany sandstone of the Devonian, while the lower slopes and the river valleys are formed of and in the Devonian shales, which also form the slopes and crest of the Shenandoah mountain.

The following table from U. S. Geological Survey, Franklin folio by N. H. Darton, shows the order of the formations and thickness as exposed in this county:

PERIOD.	Formations.	Names Used by U. S. Geological Survey.	Thickness in Feet.
Carboniferous	Pottsville conglomerate	Blackwater formation	400
	Mauch Chunk shales	Canaan formation	1,200 to 1,300
	Greenbrier limestone	Greenbrier limestone	325 to 410
	Pocono sandstone	Pocono sandstone	85 to 700
Devonian	Catskill	Hampshire formation	1,600 to 2,200
	Chemung shales	Jennings formation	2,100 to 3,800
	Hamilton shales	Romney shale	1,000 to 1,300
	Oriskany sandstone	Monterey sandstone	200 to 300
Silurian	Lower Helderberg limestone Salina Niagara limestone	Lewiston limestone	700 to 1,250
	Clinton	Rockwood formation	65 to 550
	Medina	Cacapon formation Tuscarora formation Juniata formation	200 to 350 250 to 450 685 to 1,125
	Hudson river	Martinsburg shale	1,100 to 1,500
	Trenton	Shenandoah limestone	1,300

Trenton. The Shenandoah limestone and Martinsburg shales in this county are found only on the top of North Fork mountain, and here, according to Darton, form the top of a broad arch or anticline which makes up this mountain; though both formations are removed by erosion from the north end of the mountain, and the anticline is there much steeper. Darton describes the limestone as dark blue, drab or gray in color, quite pure in composition, with the beds varying in thickness from a few inches to several feet. He states that the principal outcrop extends from opposite the mouth of Seneca nearly to Circleville, a distance of 12 miles, with a maximum width of 2 miles. The limestone in its upper part is fossiliferous, and contains numerous sink holes, especially on the western slope of the mountain. The Martinsburg shales, according to Darton, are exposed at many places along the crest of the North Fork mountain, where erosion has cut through the overlying measures, and especially in the stream valleys on this mountain. The formation consists of gray shales thinly bedded and fissile. In the upper part occur massive strata of sandstone, varying in thickness from a few inches to 4 feet.

Medina. Above the Martinsburg shale is the Medina formation of the Upper Silurian, which is found on North and South Fork mountains near the top of the ranges. At the base is a group of red sandstone and shale which is named the *Juniata formation* by the U. S. Geological Survey. Mr. Darton gives the following description of the Juniata in the Franklin folio:

"The rocks of the formation are red sandstones and shales, interbedded in no regular succession. The sandstones are hard, moderately coarse grained and occasionally cross-bedded. They vary in thickness from 1 to 20 feet, and are in greater part in beds from 1 to 4 feet thick. The shales vary in thickness from 6 to 8 feet to a thin parting between sandstone layers. Much of the formation consists of alternations of 4 or 5 feet of shales and 8 to 10 feet of sandstone. The proportion of shale increases to the northwest and the sandstone beds become thinner in that direction."

This formation is well exposed in a small area in the deep cut of Props Gap southeast of Franklin, and there consists of highly tilted layers of red shale and sandstone layers, but its best exposures are found along the sides of the crest of North Fork mountain. Over these red sandstones and shales is a very hard, light colored sandstone or quartzite, the *Tuscarora quartzite,* which forms a long narrow outcrop on the east slope of the North Fork and a very narrow ridge on the west slope of the South Fork mountain. The slope for some distance below is strewn with its boulders of disintegration. It forms the crests of many of the smaller ridges, and is a yellowish white rock very close grained. Darton states that on the west side of North Fork mountain this quartzite forms a line of vertical sharp ridges with jagged edges well exposed at the "Rocks of Seneca" at mouth of Seneca Creek, where there are vertical walls of white quartzite over 200 feet in height facing westward. At the northern end of South Fork mountain the quartzite forms high cliffs, but further south the cliffs are lower and the rock forms a wall or narrow ridge.

At the top of the Medina is a red sandstone called by the government geologists the Cacapon sandstone. It is a hard close grained, brownish red sandstone, almost a quartzite and contains scattered small pebbles. It usually shows a distinct banding parallel to the bed and splits readily along these planes. A system of cross joints causes the rock to break out in square or oblong blocks, similar to the Clinton iron ore. It is thus frequently mistaken by prospectors for iron ore, and it has a higher gravity than the other sandstones in the mountain. Its outcrop is usually marked by these blocks formed by weathering action, and the line of contact with the formations below and above is obscure. The removal by erosion of the overlying Clinton formation exposes this sandstone near the top of the South Fork and North Fork mountains, and also on the ridges between, especially in the southern part of the county. Some of the reports of cliffs of red hematite near the top of the ridges in certain

gaps, on investigation, were found to be cliffs of this red sandstone.

Clinton. The Clinton formation of the Upper Silurian outcrops on both slopes of the North and South Fork mountains near their top, and is also found in a number of the smaller ridges. It consists of buff shales, limestones, thin sandstones and beds of fossil red hematite.

At the top is a hard sandstone, buff to grayish white in color and 6 to 12 feet thick. Along Friends run the line of contact between this sandstone and the Clinton shales is well exposed, but usually the blocks of sandstone have broken and rolled down so that it is difficult to measure its thickness. The shales are flaky or fissile and the iron ore forms a bed or in places two beds in these shales. The limestone members are not always present and are thin. The iron ore is full of fossils and breaks in rhombic slabs of variable thickness, which split easily parallel to the bed. The color is a bright red to a brownish red, and texture usually granular. In thickness the ore bed varies from a few inches to 5 or 6 feet, but the average is near 30 inches.

Lower Helderberg Limestone (Lewiston) is well exposed along the lower slopes of the North and South Fork mountains and forms high cliffs along nearly all the streams cutting back into the mountains. It is slaty blue to black in color, very cherty in the upper portion, while the lower part is an ordinary bedded limestone, valuable for lime and flux. North of Franklin, in the South Branch valley, it forms the walls of the river at a number of places. (See plate II.) Just east of town the limestone cliffs are high and almost vertical. Some of the beds are very fossiliferous and numerous caves are found which can be followed far back under the mountain. Some of these are said to have been worked during the war for salt-petre or nitre found on their floors.

Oriskany Sandstone of the Devonian forms a conspicuous ledge on the mountain ridges where it stands as a narrow vertical cliff of irregular outline forming the divides. It breaks into large blocks forming a very rough slope and one difficult to travel over. It can be traced nearly the entire

length of the South Fork mountain, and is a convenient guide for following the outcrop of the limonite ore which lies next to it. It is sometimes a brownish yellow, more or less porous rock carrying fossils, and again is a hard compact white or yellowish white rock.

Hamilton Shale (Romney) forms the surface rock of most of the South Branch valley. The shales are gray to black in color, but weather buff, and break in thin laminae. Where crushed and folded, the shiny black color gives the shale the appearance of coal which has led to coal prospecting in the past. In some places limestones occur but these are thin and apparently not continuous. The higher shales of the Devonian and the Carboniferous strata are not exposed in the iron ore district, but are found to the north and also to the east and west of the ore belts, in the Allegheny and Shenandoah mountains.

The iron ores of Pendleton county are found in form of red fossil hematite in the Clinton, and as brown hematite or limonite along the line of the Oriskany sandstone. They have been opened in numerous prospect pits and trenches, but have never been mined on commercial scale, nor is there any record of a furnace ever being built. Reports on quantity and quality of these ores in the past have been somewhat conflicting.

STRUCTURE. Sedimentary rocks like those described above are horizontal in direction, or inclined or tilted, the angle of inclination being called the dip. Where the rocks are folded upward so that the rocks dip opposite directions from the line along the center of the fold, the structure is called an anticline, and where the fold is downward so that the rocks dip toward the central line, it is called a syncline. In this mountain area there is a series of folds, anticlines and synclines, illustrated in figure 5. According to Darton, in the Franklin folio of the U. S. Survey: "There are six general structural provinces in the region: the wide syncline of Shenandoah Mountain; the general anticline of South Branch Mountain and Long Ridge; the syncline of Middle Mountain; the anticline of Cave Mountain; the great overturned anti-

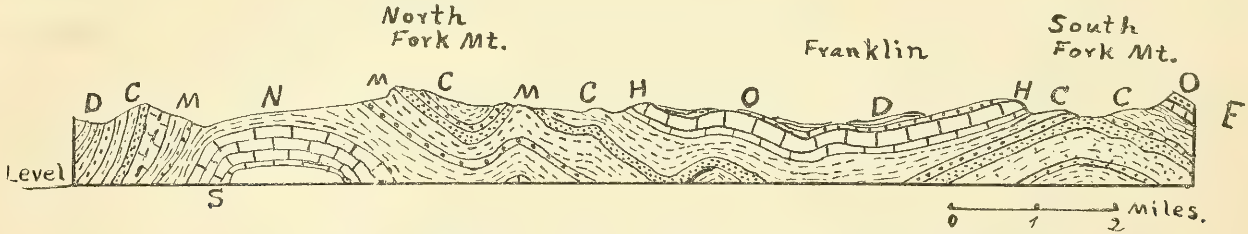

Fig. 5. Geological section just south of Franklin, Pendleton County (from U. S. G. S., Franklin Folio).

D. Devonian shale.	M. Medina.
O. Oriskany sandstone.	N. Martinsburg shale.
H. Helderberg limestone.	S. Shenandoah limestone.
C. Clinton.	

clines of North Fork Mountain, and the wide undulating syncline west of the North Fork of Potomac river. These general flexures bear subordinate corrugations of various orders, which give rise to features of greater or less prominence. The axes of all the flexures trend northeast and southwest."

Bibliography. Prof. W. B. Rogers, in his reports of 1838 to 1840, makes brief mention of the limestones and existence of valuable iron ores in Pendleton county, but gives no detailed account of the area. In 1876 an English engineer, A. R. Guerard, made a rapid survey of the area, examined and selected specimens of iron ore for a brief report for the Centennial book on Resources of West Virginia, edited by M. F. Maury and W. M. Fontaine. In the 80's the area was examined by Moore and Edwards for the Baltimore and Ohio railroad company and the various pits and trenches opened under their direction.

In 1890 and 1891 another report was made by Dr. Edward Orton, of Ohio, and H. B. E. Nitze, of North Carolina, for the same railroad. In the course of this work new openings were made and the old pits reopened. The original of this report was destroyed in the Baltimore fire and a copy was found in Petersburg, which accompanying letters show to be authentic. Many of the valuable notes of this report are incorporated in this chapter and will thus be preserved, since both the authors have passed away, and the writer takes pleasure in restating the valuable work of these two former friends. All of these men in the two reports reached the conclusion that the iron ores would not justify the construction of a railroad into the county. At that time Lake Superior ores were supplying the furnaces of the north, and basic open-hearth steel represented a minor feature of the industry. These non-Bessemer ores at that time were regarded as a very doubtful proposition. Since 1891 no reports on iron ores have been made in the area and no careful survey of the iron ores made until the present work of the State Geological Survey.

In 1897 Mr. N. H. Darton's report on the Franklin

quadrangle was issued in folio form by the U. S. Geological Survey. This quadrangle includes the greater portion of Pendleton county and portions of Grant and Hardy counties. It includes a discussion of the geology, topography and mineral resources with topographical, geological and economic maps. This report has proved of great value in the present work and is frequently quoted in this chapter.

MINES AND PROSPECT OPENINGS.

In connection with the work of the mining engineers and geologists in the preparation of the railroad reports above mentioned, a force of men was employed to open trenches and pits at various places where good exposures of the ores might be found. The last of this work was completed 16 years ago. The openings were for the most part shallow, so that at the present time they are filled more or less completely by earth, debris and water. A number of these old openings still show the ore, and some filled with earth and leaves were reopened in the course of the present work, permitting an examination of the ore and its enclosing walls.

Unfortunately for the continuity of the work, these openings are scattered over the area often several miles apart; while in the interval between them, the soil, debris and weathered rock boulders and fragments have concealed the ore bed. Its presence is only indicated by loose boulders or blocks of iron, mostly out of place.

In no place were borings made, nor is the ore exposed in ravines or gorges, so as to permit any estimate as to the depth of the ore bed, and samples can only be obtained for a few feet below the surface. No conclusion can, therefore, be reached as to the quality or width of the vein except near the surface. With all these baffling conditions present in this county, it is impossible at the present time to more than offer a suggestive outline of the Pendleton county ores. From the samples which were taken as carefully as possible to give average results, it is possible to partially judge the quality of these ores. The quality will probably not change materially for some depth and conclusions based on these

analyses may be taken as very nearly correct in any decision as to the value of these ores so far as quality is concerned.

Any estimate as to quantity must be taken with much allowance for error, and cannot be proved until the area is drilled. While previous reports have condemned the area on account of quality, but more on account of quantity, there can be but little question as to the value of the ores in quality for pig iron for open-hearth steel. As to quantity, there are a number of lines of evidence which indicate that careful prospect work with a good force of men and with the drill will reveal a very large quantity of ore. The various openings made will now be described, together with the suggestive evidence of a large extent of ore.

RED FOSSIL HEMATITE (CLINTON ORE).

Ami Smith Prospect. The fossil red hematite of the Clinton formation is reported from a number of places in Highland county, Virginia, and has been traced by prospectors and geologists north into Pendleton county. Not far from the south line of Pendleton county on one of the ridges of the South Fork mountain locally called Bull Pasture mountain just east of the Thorn valley, a prospect opening was made on the high knob just south of Ami Smiths' house and on his land.

The Smith prospect is 220 feet above the county road, and 660 feet (barometer) above the Thorn valley near the Johnstown store. The location is two miles southwest of Sugar Grove and ten miles almost due south of Franklin, or 16 miles by the county road. It is opened in the form of a trench with east and west direction cutting across the direction of the ore bed which runs N. 30° to 40° E.

The ore is brownish red to red in color, coarse grained or scaly and carries few fossils. It breaks into blocks especially along two joint planes which run N. 30° W. and N. 70° E. The hanging wall consists of flaky buff or yellow shale, fine grained and compact, while the foot wall appears to be a harder shale. The thickness of the bed as now exposed is 2 feet, 8 inches, though Nitze, in his report made when the

trench was first opened, measured the bed as 5 feet with 3 to 3½ feet of good ore. The trench has caved badly and at the upper end was 13 feet deep to the ore, so that its thickness was probably greater at that point which is now filled with rock and debris. A few small openings were made at other places on this hill and on the south side the ore is at the surface.

Nitze sampled this ore on its outcrop over a distance of four miles to the south, and gives the following analysis made by N. W. Lord, of the Ohio State University, of the samples over the four miles of outcrop:

	Per Cent.
Metallic iron	53.40
Silica	11.70
Phosphorus	0.321
Manganese	0.106

At the time of the present examination samples were taken of the ore in the upper part of the trench and also from the large pile of ore on the dump which was taken out of the trench through its length and depth and represents very closely the average of the ore at this place. The final average sample was analyzed in the Survey laboratory with the following results:

	Per Cent.
Metallic iron	52 14
Moisture	0.50
Loss on ignition	3.26
Silica	13.36
Iron oxide	74.48
Lime oxide	1.22
Manganese dioxide	0.03
Sulphur	0.001
Phosphorus	0.32
Titanium oxide	0.11

A. J. Pitzenbarger Prospect. Five miles northeast of the Smith prospect, the red fossil ore was opened in a number of pits on the lands of John and A. J. Pitzenbarger. The ridge through these farms is locally called Sharp Ridge and the Clinton formation is cut into by a deep ravine formed by one of the branches of Dry Run. The ore was found over the surface in numerous blocks on the south side of the run.

on the Pitzenbarger lands. Scattered blocks of ore may be traced over a distance of 300 feet, and the ore bed is very near the surface as a number of shallow openings one or two feet deep show the ore in place. One deep open drift was made for a distance of 15 or 20 feet south into the hill and shows 30 inches of red hematite dipping to the west 30° and runs in a direction N. 30° E. Over this ore is one foot of red sandstone much resembling the ore except for its sandy character, and over the sandstone, 6 feet of fine buff shales are exposed. The foot wall is apparently shale. The man who had charge of the work of this excavation states that at the point farthest back in the hill, the ore was 6 feet thick, but this is completely covered at the present time, and the measurement could not be verified. The ore is increasing in thickness from the edge of the hill as far back as it could be examined, and at this point was 30 inches thick.

The ore is fossiliferous and breaks in the characteristic block form with the joint planes N. 30° E. and N. 45° W., and it splits readily into thick or thin plates. Mr. Nitze gives the following analysis of the ore from the surface shallow pits at this place as analyzed by Lord:

	Per Cent.
Metallic iron	55.40
Silica	7.45
Manganese	0.10
Phosphorus	0.425

The entry was driven into the hill after Nitze's report was made, and the following analysis was made in the Survey laboratory from an average lot of ore from this entry. The second analysis gives composition of the ore to west of Pitzenbarger house:

	Ore in Entry.	Near House.
Metallic iron	52 03	55 21
Moisture	0.35	0.50
Loss on ignition	6.36	3.85
Silica	9.64	9.14
Iron oxide	74.35	78.88
Lime oxide	1.76	0.94
Manganese dioxide	0.02	0.04
Sulphur	0.06	0.02
Phosphorus	0.74	0.76
Titanium oxide	0.18	0.14

Passing over the hill northeast across the county road, blocks of fossil ore are found in the field to the west of A. J. Pitzenbarger's house. Numerous blocks are turned by the plow and the ore is under shallow cover through this area. The outcrop, except as lost in passing over the high hill, was thus followed a mile, and the farmers of that section state it can be followed in a similar way for two or three miles further northeast.

Iron Knob or Bowman Prospect. Four and a half miles northeast of the Pitzenbarger openings is the Iron Knob prospect opening on the T. F. Bowman land. This point is at the head of Props Gap, just south of the county road from Franklin across the South Fork mountain to Brandywine in the South Fork valley. It is six miles by road or three and a quarter in air line course from Franklin, and on the portion of South Fork mountain locally called Dickerson Mountain.

This location has long been regarded as a most valuable iron area. The farmers on this mountain state that in heavy storms, lightning commonly strikes along this ridge. It is also a common story, known throughout the county, that before the war a Mr. Dickerson, who had a blacksmith shop on the road below this knob, smelted some of the ore and made a horse-shoe which was sent to Richmond and there hung for many years in one of the offices in the Capitol building. The son states that his father made a number of articles of iron from this ore, reducing it in his forge. It was from this place that samples of ore were taken and sent to the Chicago World's Fair, and were there awarded a medal on quality.

Blocks of ore are found at a number of places along the ridge and an opening was made on this knob 18 or 20 years ago, and which was partially reopened for the present work. The vein here is nearly horizontal and was opened by a trench 35 feet long which shows good ore from west end to a point 25 feet east. The direction of the bed is not clear but it apparently runs N. 30° to 40° E. The ore is brownish red in color with layers full of fossils which are mostly replaced by iron, and breaks into blocks along two sets of joint planes

N. 60° to 65° E. and N. 20° W. It rests on shales and has 4 feet of shales over it which are of the usual type of yellow or buff flaky shale breaking up into small pieces. The thickness is usually stated as 24 inches, but present measurements show 19 inches, though this may increase a little as followed further under heavier cover of shales.

The level of this opening is 1,100 feet above the town of Franklin. Pits sunk further north also showed the ore. This ore, as analyzed by Lord in the Nitze report, had the following composition:

	Per Cent.
Metallic iron	54.90
Silica	7.10
Phosphorus	0.572
Manganese	0.070

Samples were taken for the present work from the trench and the pits, and quartered down so as to secure an average. This was analyzed in the Survey laboratory with the following result:

	Per Cent.
Metallic iron	57.09
Moisture	0.52
Loss on ignition	2.75
Silica	6.07
Iron oxide	81.59
Lime oxide	1.30
Manganese dioxide	0.04
Sulphur	0.01
Phosphorus	0.59
Titanium oxide	0.11

Following the direction of this ore to the northeast, it has not been opened and no outcrops were found until reaching the Hiner farm, just south of Trout run and 3½ miles northwest of Iron Knob. Here in the farm road a 12-inch vein of red hematite was found trending N. 30° E. Its upper wall on the east was formed by the buff flaky shales, while the foot wall was a shaly brown sandstone which soon changes to a solid gray coarse sandstone to the west. The vein dips east about 40°.

The width and character of this ore do not correspond with the vein as seen on Iron Knob to the south, and may represent a second bed. Nitze, in his work on Iron Knob, had a number of pits opened to the east of the 19 or 20-inch bed and found a second bed of red hematite 10 to 12 inches thick and standing nearly vertical. These pits were closed and in the present work could not be located, so that only one bed was found on Iron Knob. If this thin bend on the Hiner farm corresponds to the smaller bed on Iron Knob, the wider bed should be found to the west, but in this direction the rocks are more or less concealed.

Nitze states that the outcrop of the fossil red hematite can be followed north to Deer Run P. O.. but that the ore is very sandy. He also followed the outcrop six miles further north by loose boulders, but did not find the ore in place. The bed apparently disappears a few miles south of the Grant conty line, but comes to view again eight miles north in Grant county.

North Fork Mountain. The Clinton formation is found along both slopes of the North Fork mountain and blocks of ore are reported from a number of places so that the ore is probably found over most of the length of the mountain, but no openings have been made except to the west of Franklin. The country is almost inaccessible and entirely so after a few days rain as the rivers must be forded back and forth, and the roads are lightly travelled and then usually on horseback. Prof. Orton and Mr. Nitze made trips to a number of localities where ore was reported and only found loose blocks of sandy ore mostly in small pieces. They report that on the most western outcrops the red ore is very thin and impure, the sheet having thinned out to a knife edge on the western slope of the mountain.

Bible Knob Prospect. Near Bible Knob, in the county road opposite the barn of T. S. Simmons, the fossil red hematite was exposed in a shallow pit. This point is about 4 miles due west of Franklin, or 6 miles by road. The rock runs N. 30° E. and the opening was made in the buff shales and showed blocks of red very sandy ore, associated with a soft yellowish

brown sandstone full of fossils. The bed is not well defined in this opening and its thickness could not be determined. The composition of this ore, according to Survey analysis, is as follows:

	Per Cent.
Metallic iron	50 07
Moisture	0.90
Loss on ignition	4.39
Silica	11.74
Iron oxide	71.36
Lime oxide	2.46
Manganese dioxide	0.04
Sulphur	0.03
Phosphorus	0.67
Titanium oxide	0.07

Mr. Nitze made another opening further south, near Smith Creek, on Job Hartman's land near Wilfong's Knob, but this place has evidently caved in and could not be located in the present work. Mr. Nitze, in his report, describes the formation in this opening as follows:

	Inches.
Upper layer, good ore	9
Middle layer, sandy ore	5
Bottom layer, slaty ore	14
Total thickness of the seam	28

The foot and hanging walls are green shales, with strike, or trend of vein N. 20° E. and dip 22° south, 70 degrees east. Elevation by barometer 685 feet above Franklin and 170 feet above Smith's Creek. He states the opening is about three miles and a half from the South Branch down Smith's Creek to its mouth, which is two miles southwest of Franklin.

A third opening was made by Mr. Nitze on Wagner Knob one mile west of South Branch of Potomac, near Hammer's run on the Henry Moyer land. This locality was not visited in the present work, but it is described as follows by Mr. Nitze:

Hanging wall	green shales.
Good ore	5 inches.
Dirt and clay	4 "
Sandy ore	18 "
Foot wall	green shale.

Dip southeast and strike or course N. 25° E. Elevation above Franklin 835 feet. Mr. Nitze gives the following analysis made by Lord of an average sample taken of the good ore over 15 miles of outcrop:

	Per Cent.
Metallic iron	51.80
Silica	11.00
Phosphorus	0.408
Manganese	0.050

Mr. Nitze makes the following observation on this analysis: "The quality of the ore, therefore, leaves nothing to be desired, but the thickness of the good ore from 5 to 9 inches only, precludes any idea of working it on an economical basis. At the same time it will be observed that the ore bed is thickening eastward." East of the Wagner Knob locality, the ore dips under the South Branch and comes to the surface on the slopes of Jack mountain in three lines of outcrop. The length of the Clinton outcrop at this place, according to the map of N. H. Darton, is 3 miles, and just north of Moyer's Gap, it is concealed by the overlying Lower Helderberg limestone, and the Clinton is not seen again in this direction.

This outcrop was not examined in the present work, but Mr. Nitze states that he found the red fossil hematite as follows: "About a half mile southwest of Moyer's Gap I found the ore on Martin Moyer's land, and about one mile nearly west of here on Lewis Moyer's land I found profuse surface indications distinctly traceable for 100 yards or more, showing a double outcrop probably on an anticline. About three miles southwest of Moyer's Gap, in a line with the most easterly outcrop near John Moyer's house profuse indications were found in a hollow near a branch. I had an opening made here which showed as follows:

Hanging wall	green shale.
Good ore	6½ to 9 inches
Green shales	7½ "
Good ore	3 to 4 "
Slaty ore	4 "
Green shales	9 "
Slaty and sandy ore	5 to 6 "
Foot wall	green shale.

Total good ore, 9½ to 13 inches; dip 39° south, 65° east; strike N. 25° E.; elevation above Franklin, 1,100 feet by barometer."

Mr. Nitze describes the ore as very finely oolitic and gives the following analysis by Lord of an average sample:

	Per Cent.
Metallic iron	53.70
Silica	11.20
Phosphorus	0.268
Manganese	0.40

The following notes on the Clinton red hematite ore along Jack Mountain southwest to the county line and in Highland county, Virginia, are taken from the report of Mr. Nitze: "About two miles southwest of the Moyer opening, on Peter Harper's land, I traced this ore over a distance of about half a mile. It has lost its oolitic character here and was rather sandy. About one and a half miles still farther southwest I found the same sandy fossiliferous ore on George Halterman's land, barometrical elevation above Franklin about 1,500 feet. About seven miles southwest of here, in Highland county, Virginia, two and a half miles northeast from Monterey in the same line of strike, I found the red fossiliferous Clinton ore on Mr. Sipe's place on the western foot hills of Jack Mountain range. About four and a half miles southwest I found it again on Wm. A. Beverage's land, where the ore was rather sandy and the blocks thin. This makes a total distance of about 17 miles over which I traced this outcrop of the red fossil ore. It continues in a southwesterly direction, but I had not time to examine it further. According to the above analyses, the quality of the ore is good, but the opening and general indications along the whole line of outcrop show that the bed is not thick enough to work economically; but at the same time again proving the fact previously stated that the seam of good ore is thickening eastward."

QUANTITY OF CLINTON ORE AND POSSIBLE OUTLETS.

In the South Fork Mountain, the Clinton red hematite ore bed can be followed from near the south line of the county to within a few miles of the north line, a distance of 24 miles; by outcrops and prospect openings more or less separated from each other. Where outcrops were not found, loose pieces of float ore have at a number of places indicated the presence of the bed.

The maximum width reported is six feet, but the maximum measured in the present work was 30 inches at the south, 20 inches at center and 28 or 30 inches at the north. If the average thickness be taken as 24 inches, and if it is assumed that the bed is continuous and workable to a depth, or better, a width of 700 feet, there would be in this red hematite bed in South Fork Mountain in Pendleton county, about 6,750,000 cubic yards of ore. If one cubic yard of this ore weighs 3 tons, there would be 19,710,000 tons of ore, which would last three blast furnaces with 500 tons each daily capacity over 40 years. If a value of one dollar per ton be placed on this ore it would represent a value of $19,710,000 for one of the undeveloped resources of this county, not including the value of other iron ores also present.

Mr. Nitze, in his report, suggested that six miles of this outcrop should be discarded in any estimate on account of the sandy character shown on the scattered blocks over the surface; but in this six miles the ore was not opened and the surface blocks probably came from the top of the vein, which is partially leached of its iron and which is often higher in silica than the main portion of the vein. As has been stated, the entire line of outcrop should be carefully followed and opened frequently to be positive as to thickness, quality and continuity, though there appears to be little reason to doubt the last condition.

The above estimate, therefore, only represents an approximation to the real quantity of available red hematite Clinton

ore, and its value is suggestive. To this extent, it certainly shows that this field cannot be condemned on present knowledge. One objection often brought forward against an estimate of quantity of Clinton ore from surface examination is the fact that in Alabama, Pennsylvania and to some extent in Virginia, the rich ore is near the surface and gradually decreases with depth with percentage of lime carbonante increasing until the ore is replaced by limestone. In most of this area the ore vein is nearly horizontal or with low angle of dip and as far as followed across the bed shows but little change. There is little or no evidence to show that the ore represents a replacement of a limestone stratum by iron and the ore bed is probably continuous for a considerable distance, possibly several times the figure used in the above calculation (700 feet).

There are a number of factors which make this estimate conservative. First, the belt of Clinton rock to the west is omitted as it has never been carefully prospected, but it may yet show the continuation of this same ore bed on the other limb of the anticlinal fold. Second, the surface thickness of the ore seam may increase under greater depth of cover. The opening into the hill on the A. J. Pitzenbarger farm shows an increase from 20 inches to 30 as followed into the hill, and is probably more than this at the farthest point formerly opened if the testimony of the workmen is reliable. Third, the estimate of 700 feet width is probably below the actual width as the horizontal outcrop of the Clinton formation runs 1,000 to 1,500 feet and it continues even further beneath the other strata. The ore bed may possibly be coextensive with these beds of shales and sandstones associated with it. The above estimate or ore tonnage will, therefore, doubtless prove much greater in actual development.

An additional supply of Clinton hematite ore will probably come from Jack and Simmons mountain to the southwest, but the small amount of prospect work there has not yet shown veins of workable width. The Clinton ore on North Fork Mountain is usually thin and sandy and is of

Plate III.—A.—Brown Hematite Ore Bed on Hiner Land South of Franklin, Pendleton County.

Pla III.—B.—Open cut at Monument Mine, Beaver Lick Mountain, Pocahontas County.

very doubtful value, so that it is omitted in this estimate of the Clinton ore supply of the county.

Flux. The Lower Helderberg limestone found on the lower slopes of the mountain would be available for furnace flux in the treatment of these ores if the furnaces were located in the county. If the ores were shipped to Keyser where they would be brought nearer the coke fields of the Western Maryland railroad, a high grade limestone (Lower Helderberg) forms high cliffs near this city.

Outlets for the Ore. There is no railroad in Pendleton county though a number of surveys have been made in the past 20 or 30 years. There are several practical north and south routes for a railroad with easy grade. From Keyser, the New Creek valley can be followed back through Grant county passing through the New Creek Mountains by way of Greenland, Cosner or Kline Gaps and following the Patterson Creek valley to Petersburg, thence up the South Branch valley past Franklin, a distance of probably 75 miles to Franklin.

The Baltimore and Ohio branch from Green Spring on the main line to Romney in Hampshire county could be extended up the South Branch valley to Moorefield and Petersburg, and thence up the same valley to Franklin, thus passing through a rich farming country and two ore regions, reaching three county seat towns. Within the past two years a road was chartered to follow this line to Petersburg and the right of way located, but no further work has been done to the present time. The distance by this route from Romney to Franklin would be about 60 miles or 76 miles from the main line roads at Green Spring Junction on the Potomac.

From the south a road could be built from the Chesapeak and Ohio line. A lumber road now extends from White Sulphur Springs northeast 25 miles to Columbia Springs, and with low grades and a few deep cuts would reach Jackson river and follow this up within 4 miles of Monterey in Highland county, Virginia, where the road could pass through Vanderpool Gap to the South Branch valley, following this down to Franklin where it would connect with either line

north to the Baltimore and Ohio and Western Maryland main lines. Such a road would be about 110 miles long to Franklin, or 185 miles to the Potomac, including the 25 miles lumber road which is standard guage. Such a line would be a north and south connecting line between these great east and west systems and would bring the Pocahontas and New River coke north and pass through the undeveloped iron districts of Greenbrier, Pendleton, Grant or Hardy counties, West Virginia, Highland and Bath counties, Virginia, as well as through a rich timber district and farming valleys. It would bring the coke and iron together.

East and west railroads connecting the West Virginia coal and coke fields with the Southern railroad in Virginia, have been surveyed a number of times, and if built would bring coke over a short haul to the iron. Such a road crossing the north and south mountain ranges would be very expensive in construction, involving heavy grades and tunnels, though gaps could be utilized in all the ranges with the exception of the Allegheny Mountains, and engineers claim that this range can be crossed within a practical cost estimate.

The ores can be brought from the mountains by tram roads and inclines to a main line in the valley, by passing down through a number of gaps. The differences in elevation between the ores and the South Branch valley is 1,000 to 1,500 feet.

RED NON-FOSSILIFEROUS HEMATITE (CLINTON).

Near the contact of the Clinton and Lower Helderberg limestone there is a deposit of red hematite very close grained, and lacking the granular or scaly structure of the fossil hematite, and with no trace of fossils. Except in color it resembles the brown hematite and usually breaks with parallel planes, giving the ore a shaly appearance. It was observed at a few scattered places, but apparently exists in large quantities at these points. More of these deposits will doubtless be found in careful prospect work along this line of contact. In the present work two of the openings made on this ore were visited.

Hiner Prospect. On the east slope of Jack Mountain about one and a half miles southwest of Moyer Gap and eight and a half miles southeast of Franklin, or 11 miles by road, an opening has been made in this ore on the B. H. Hiner land, locally known as the Big Survey. It is on a ridge just east of a small settlement known as Moatstown.

The ore has been exposed by a trench 15 or 20 feet long, and then north by pits over a distance of a few hundred yards, and the bed runs about N. 30° E. The upper part of the ore is in the form of rounded boulders, and below appears to be a solid bed of ore opened with a width of 12 to 15 feet. The cover was very shallow and there is apparently a very large body of ore at this place. (See plate III.—a).

The bed dips about 60° southeast, and in places stands nearly vertical. The upper pit on the hill is 63 feet above the ore in the lowest pit opened. The level of the upper trench opening is 207 feet above the houses at the settlement and 850 feet above the level of the town of Franklin. The bold ledges of ore as now uncovered represent the most striking ore outcrop in the county, and the people in this area look upon this place as a mountain of ore. The tonnage of ore in this hill as now exposed is about 50,000. This ridge ought to be prospected by openings to the north and south, as the ore is only opened over a distance of 400 or 500 feet, and showed in large quantities at both ends of the line of pits. This is a very promising field for prospect work and the available tonnage may prove large.

This ore was sampled from the trench and pits and had the following composition as determined in the Survey laboratory:

	Per Cent. Hiner Ore.	Per Cent. Eye Ore.
Metallic Iron	41.22	42.44
Moisture	0.45	0.53
Loss on ignition	3.92	4.28
Silica	26.76	25.40
Iron oxide	58.90	60.65
Lime oxide	0.30	0.34
Manganese dioxide	0.02	0.34
Sulphur	0.07	0.11
Phosphorus	0.17	0.33
Titanium oxide	0.21	0.29

Dave Eye Prospect. In the South Fork Mountain three and a half miles southwest of Iron Knob and five miles almost due south of Franklin, the fossil red hematite is opened on one side of a small ravine on the Pitzenbarger land, while across the ravine to the northwest on the Dave Eye farm, the shaly red hematite outcrops just below the Lower Helderberg limestone which is the rock formation of this so-called Sink Hole Ridge or Mountain.

The opening was driven northwest across the bed and showed a very fine grained compact red and reddish brown ore with thin black seams through it, and has the appearance of a reddish limonite. Some fragments of the ore are brown, giving the impression of an ore body composed of a mixture of red and brown hematite. A similar association was noticed on Trout run in Hardy county. The explanation suggested by this mixture is a former bed of limonite changed to hematite, but the change was incomplete. The ore is similar to that in the Hiner prospect and breaks along shaly planes. Its composition is shown in the above analysis.

These were the only places where an ore body was observed along the Clinton-Lower Helderberg contact, but Nitze found a few other deposits 12 miles northeast. He mentions one a mile and a half west of Deer Run valley which he traced for two miles by surface boulders indicating a large deposit. His sample at this place and also two and a half miles further west on the Bird Eye farm on Fisher Mountain were analyzed with the following results:

	Deer Run.*	Eye Farm.**
Metallic iron	41.60	46.75
Silica	25.95	27.22
Phosphorus	0.209	0.164
Manganese	0.050	0.148

*Analysis by Lord. **Analysis by Ricketts.

BROWN HEMATITE, ORISKANY ORES.

The brown hematite iron ores are found in this county near the line of contact of the Oriskany sandstone and the Lower Helderberg limestone, apparently replacing this lime-

stone. The hard Oriskany sandstone usually forms an abrupt and steep cliff or ridge, and is the crest or backbone of a number of the minor mountain ridges. This rock forms an important guide to the ore, and at many places is full of casts of fossils so that it can be distinguished from the Medina sandstone which also forms ridges but is almost entirely devoid of fossils. From the association of these ores with this sandstone they are usually called the Oriskany ores, though they belong more properly with the limestone. It is this group of ores that are now worked in the various furnaces in Allegheny county, Virginia, 60 to 65 miles southwest of Franklin.

The ore is a deep brown to reddish brown color often with black glistening patches through it, and varies from a spongy honeycomb structure to a very compact and close grained ore. In surface outcrops it is often broken or weathered into rounded boulders separated by dirt seams. Where prospect openings are deep enough, the ore appears in a more solid bed.

Whether this ore forms a continuous belt or belts northeast-southwest across the country along the lines of contact of the Oriskany and Helderberg, is uncertain. This line of contact is usually covered by the debris of the sandstone and the soil and rock fragments washed in by heavy rains, so that it cannot be examined except in a few scattered localities. In past exploration of this county, very little attention was given to these ores and very few prospect openings were made. Nitze concluded that the brown hematite Oriskany ores in workable quantity did not exist with any continuity. Darton, in the Franklin folio, states that "a careful examination of the entire area of the formation indicates that there is no prospect of deposits of economic importance."

However, with these adverse conclusions, where this line of outcrop is approached in many places along South Fork Mountain, nodules and boulders of ore are found, and there are not many miles of the outcrops where such nodules are not found. It seems almost certain that over most of the length of the outcrops, Oriskany ore is present, but in what quantity it is impossible to state at the present time.

From these surface boulders of ore and the character of the ore where exposed in prospect openings, it seems reasonable to believe that brown hematite ore will be found at nearly all places along or near this contact, but that its width and depth will vary, enlarging to workable deposits in one place, then becoming narrow or even disappearing for a distance, and again expanding into a workable deposit. Further south in Highland county, Virginia, and in Greenbrier county, West Virginia, also in Hardy and other counties to the southeast, the Oriskany ores are present in far greater quantity than any other group of ore.

If the above supposition should prove correct on careful prospecting work, there is a large quantity of workable limonite ores in the South Fork Mountains, and there is similar evidence for the existence of these ores in North Fork Mountain. While attention in the past has always been directed to the red fossil hematite of this county as its valuable asset, it has appealed to the writer that the greater value in iron ore in the county will be in the brown ores. It is due to the fact that past investigation has been mainly restricted to the red ores, that so few prospects are opened in the brown ore. It will be more difficult to exactly locate and expose the brown ores in prospect work, since the ores are associated with a very hard sandstone, and the surface is covered with the boulders of disintegration. The red hematite in the soft shales is more easily opened. The difficulty of exactly locating the line of contact of sandstone and the limestone will require a greater amount of excavation as trenches will have to be started across the line of supposed contact and extend until the ore is encountered. The heavy sandstone may, in places, completely cover this ore, making it impossible to reach it with low cost. A few good prospect openings have been made, but have not been carried to any depth, but these are now more or less completely filled with debris or water.

Dickerson Prospect. This ore was opened north of John Dickerson's house between the Hiner and Dickerson lands on a tract owned by Hon. S. A. Elkins. The openings are just east of a high ridge locally called Narrow Back, forming

the crest of the mountain at this place. It is 4 miles due east of Franklin. This long, narrow ridge is composed of sandstone in which no fossils were found, but it is apparently a ridge of Oriskany sandstone surrounded at lower level by the Helderberg limestone.

The ore was opened by four pits, 25 to 30 feet apart. In the first one at the west, three feet of brown shelly ore was found while in the other pits the ore was close grained, reddish in color and breaks shaly. Except for its relation to surrounding rocks it is quite similar to the shaly red hematite of the Clinton. It would be better classed with the red hematite than the brown. As opened, the bed is at least 50 to 60 feet wide, but it was impossible to estimate its thickness or extent. The ore is found in white and pink clays.

A similar red ore is found on the Wash Dickerson farm a mile and a half south, where it was opened by two cross trenches and here is also associated with fine white and pink clays. The ore has not been opened but a few feet in depth and is more or less nodular.

Boggs Prospect. On the Wm. Boggs land, two to three miles east of Franklin, on the sides of Little Mountain, the Oriskany ore has been opened in a number of pits and trenches. The white or yellowish white Oriskany sandstone forms a cliff just above the ore, and is full of fossils.

At the north end of Little Mountain the ore was opened in four pits and had only three feet of cover. The ore is nodular at the top and was followed 12 feet in depth in one hole. It is associated with white and yellow shaly clays. The ore is compact, reddish brown color with parallel black seams and is readily broken along these planes. The weathered portion of the ore is coated with a yellowish earthy layer.

Nearly opposite the head of Evick Gap and southwest of the last, two or three pits were made 20 to 25 feet lower on the side of the mountain. Here the ore is apparently of higher gravity and near the surface is brownish red to red in color, and was opened to west against a wall of white Oriskany sandstone on Long Mountain. There is a large body of this ore along the mountain, but outside of these

few openings it has not been prospected. In all of these Oriskany ore openings there is a mixture of the red and brown hematites, and as far as can be judged from surface ores there is far more red than brown.

These ores were analyzed in the Survey laboratory with the following results:

	Elkins Tract.	Wash Dickerson	Wm. Boggs Tract. Little Mt.	Long Mt.
Metallic Iron	34.42	38.27	33.87	37.33
Moisture	0.60	0.70	0.65	0.70
Loss on ignition	4.93	4.60	6.17	5.15
Silica	32.30	30.86	32.93	29.32
Iron oxide	49.19	54.68	48.39	53.33
Lime oxide	0.36	0.34	0.50	0.28
Manganese dioxide	0.065	0.06	None	0.035
Sulphur	0.05	0.09	0.09	0.12
Phosphorus	0.32	0.29	0.66	0.32
Titanium oxide	0.40	0.32	0.40	0.36

North Fork Mountain. At a number of places along the North Fork Mountain red and brown hematites are found in loose boulders in proximity to the Oriskany-Helderberg contact. Near Smith Creek four miles southwest of Franklin, boulders of brown ore are found which are compact and of good weight, and the farmers report that similar ore is found in the fields to the north of Friend's Creek and for a few miles further north. There have apparently been no openings made in the ore in this area.

Mr. Nitze states in his report that he traced this ore by scattered boulders, often some miles apart, from Grant county south into Highland county. On Brushy Mountain, two and a half miles northwest from Franklin, where he followed a considerable accumulation of these boulders for over two miles, he collected an average sample over the two miles which showed on analysis by Lord:

	Per Cent.
Metallic iron	45.20
Silica	18.40
Phosphorus	0.46
Manganese	0.06

Nitze also opened this ore up Peter's Run and about five miles north of Franklin where the bed was 13 to 15 feet

wide and associated with stiff blue clay. The strike was approximately N. 50° E. and dipped 45° southeast. On the South Fork Mountain eastern slope in southern part of the county, Nitze reports a solid ledge of the brown hematite of shallow depth trending N. 30° E. and dipping 61° southeast.

Nitze followed the Oriskany ore through Highland county, Virginia, into Bath county, and states that four miles southeast from Doe Hill, in the former county, the Oriskany ore comes to the surface in large quantity with the following composition analyzed by Lord:

	Per Cent.
Metallic iron	45.10
Silica	15.80
Manganese	0.580
Phosphorus	0.342

Four miles further south, the bed is only eight inches wide, but 22 miles south of Monterey, Bath county, are large deposits, and he reports promising deposits northeast along Jack Mountain.

Quantity of Oriskany Ore. From the above review of the outcrops and the prospect openings of the Oriskany ore it is impossible to estimate the depth or extent. Much more prospect work must be done before any conclusions can be drawn. As has been stated, it is probable that the ore continues northeast across the county along the Oriskany-Helderberg contacts. There is thus a strong probability of three or four lines of this ore with the most promising ores in present state of our knowledge along the eastern slope of North Fork Mountain and western slope of the South Fork Mountain. The length of each line of Oriskany-Helderberg contact is about 30 miles; or, for the two lines, 60 miles.

It would be, at the present time, useless to estimate the quantity of available ore, as such an estimate would not be founded on proved facts. It might, however, be of interest to look at the possibilities which are certainly sufficient to justify a company opening along these contact lines. The ore where it could be measured was 12 to 15 feet wide, and

has been followed to a depth of 25 or 30 feet and not any indication of the bottom of the bed.

If there should be a bed of this ore averaging 10 feet in width and 60 feet in depth over one half of the length of outcrop, this would yield 10,000,000 tons of ore, which would last two 500-ton furnaces 30 years.

Resume. Within the area of Pendleton county there are three groups of ores; the Clinton red fossil hematite, which, on a conservative estimate, should yield nearly 20,000,000 tons of ore; the non-fossiliferous red hematite of the Clinton, which has only been opened at a few places, and the Oriskany brown hematite, which will furnish a large quantity of ore, but lack of openings will not permit a reliable estimate. There is here a fine opportunity for valuable prospecting work with the great possibility of exposing large ore deposits. There is enough ore in sight to justify development if a railroad was available. Not enough work has been done on these ores to justify the construction of a railroad for the ores alone, but taken in connection with the ores in the counties to the north and south, the timber, freight traffic in other lines, the district certainly deserves careful consideration on the part of capital seeking profitable investment. The possible profits ought to justify the expenditure of sufficient capital to open these beds and determine their extent and quantity. Such work should be done in a systematic manner by a strong company.

CHAPTER VII.

THE IRON ORES in GRANT and MINERAL COUNTIES

GEOGRAPHY OF GRANT AND MINERAL COUNTIES.

Grant county, located directly north of Pendleton, was formed from a portion of Hardy county in 1866 and named in honor of General U. S. Grant. Its area is 483 square miles,[1] with a population of 7,275 and county seat located at Petersburg, in the southern part of the county.

The mean annual rainfall is 50 to 60 inches, and mean annual temperature of 40° to 50°.

The county is bounded on the north by Garrett county, Maryland, and Mineral county, West Virginia; on the east by Hardy county; on the south by Pendleton, and on the west by Tucker. The only railroad line in the county, the Western Maryland, passes along the northeastern edge for a distance of 15 miles. The distance from Petersburg to the nearest station on this road, Gormania, is 36 miles by road, or by Bayard 37 miles; but these routes are seldom taken on account of the rough roads and heavy grades. Practically all freight and pasenger traffic is from the Baltimore and Ohio and Western Maryland railroads at Keyser, which is 42 miles distant by road with a daily stage and mail line.

Petersburg can also be reached by stage with two days' trip by way of Moorefield from Romney, which is located on a branch of the Baltimore and Ohio. The distance by this route is about 38 miles. Petersburg is the largest town in the county, with a population of about 350, and has good

1 **Statistics in these sections from U. S. Geol. Survey, Bull. 233, Gazeteer of West Virginia.**

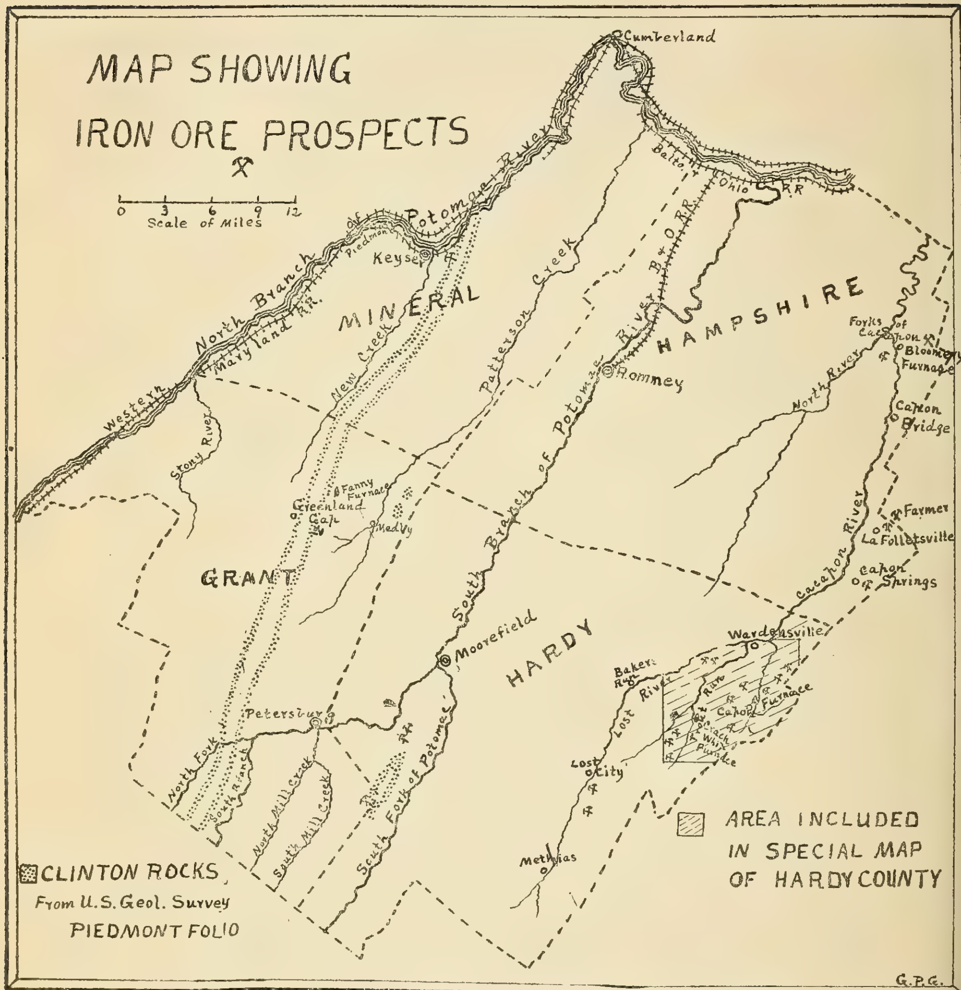

Fig. 6. Map of Grant, Mineral, Hardy and Hampshire Counties, Showing Location of Iron Ore Prospects and Mines.

stores, hotel and livery, so that it is a good outfitting point for the investigation of the ores in Grant and Pendleton counties. It is located 10 miles north of the south line of the county, 22 miles from the north line, one mile from east line, and 11½ miles from west line.

Mineral county is located north and little east of Grant, and was formed in 1866 from portions of Hampshire, and named from its mineral wealth. Its area is 323 square miles, with a population of 12,883, and county seat located atKeyser, in the north central portion of the county. The mean annual rainfall is 50 to 60 inches. and mean annual temperature 45° to 50°.

The county is bounded on the north and west by Allegheny and Garrett counties, Maryland, the line being marked by low water on the Maryland side of the Potomac river; on the east by Hampshire county, and on the south by Grant county. The Western Maryland railroad follows the county line on the north and west, a distance of 58 miles and the Baltimore and Ohio railroad on the north and west to beyond Piedmont (W. Va. Central Junction) a distance of 43 miles. Keyser, the county seat and largest town, has a population of 2,165, is located on the Potomac river and reached by the two railroads above mentioned. It is located on the northern boundary of the county, about 18 miles from the extreme northern point of the county, 12 miles from south line, 9 miles from east line and 16 miles from the farthest point on the western boundary line. Five miles northeast of Keyser is the next largest town, Piedmont, with a population of 2,115.

TOPOGRAPHY OF GRANT AND MINERAL COUNTIES.

These counties are crossed by northeast-southwest mountain ranges and valleys, with the Potomac river valley crossing at the north and running parallel at the west. The Allegheny Front range forms the western line of Grant county at the south and trends N. 30° to 40° E., across both counties. To the west of this point is a broad plateau, 3,000 to 3,500 feet

elevation, trenched by a number of streams and with a very irregular surface. The North Branch of the Potomac has cut its deep gorge in this plateau. Stony river cuts across this plateau the entire length, north and south, of the county, while Abrams creek follows a nearly parallel course across Grant and the western part of Mineral county.

The Allegheny Front rises steeply from New Creek valley at the east from a level of 1,500 feet to 4,000 feet in the main ridge in a distance of three miles at the south line of Grant county; from 1,600 feet to 3,500 feet in a distance of three miles near the center; from 1,500 feet to 3,000 in two miles at north line of Grant county. The average slope is thus 800 feet to the mile at the south, 630 feet at center and 750 feet to the mile at north line of the county. In Mineral county at Rees Tannery, about center of the county, the elevation increases from 978 feet in the valley to 3,000 feet on the Front in a distance of 2½ miles, or a raise of 800 feet to the mile. The highest knob on the range is 3,327 feet at Pinnacle Knob. The eastern slope of this range is deeply cut by numerous short creeks tributary to New creek.

The northern sloping New creek valley divide is found four miles north of Greenland Gap with an elevation of 1,950 feet. The valley at northern county line, a distance of five miles, has elevation of 1,400 feet, or a fall of 110 feet to the mile. It empties into the Potomac at elevation of 800 feet, and in this distance of 13 miles has a fall of 46 feet to the mile, or an average fall of 60 feet to the mile from source to mouth. The south flowing New Creek has its source one mile south of Kline Gap, with elevation of 1,900 feet. The distance between the heads of the two streams is 13½ miles, with the drainage between these headwaters passing to the east through the gaps in New creek range. The south flowing New creek, 7 miles long, empties into the North Fork of the Potomac at Hopeville, in the southern part of the county, at an elevation of 1,100 feet, or a fall of 115 feet to the mile. The valleys of both streams are narrow and deeply cut, though the northern creek valley becomes wider in Mineral county and the creek follows closely the east wall.

The New Creek Mountain, to the east of the valley, consists of elongated ridges cut off from each other by deep transverse valleys. It represents the continuation of the North Fork Mountain of Pendleton and southern Grant counties, the line of division being the transverse valley of the South Fork. The northern end of the South Fork Mountain has an elevation of 3,000 feet and the New Creek Mountain reaches 2,500 feet at its southern end with a few peaks, 3,000 feet. The width of the valley between the 2,500 foot contours is 1½ miles, and between the 1,500 foot contours, ½ mile. The elevation of the mountain near center of Grant county is 2,200 feet; at the north line, 2,400 feet; and south of Keyser 1,500 to 1,600 feet, and the mountain continues northeast to the North Branch of the Potomac.

In Grant county the mountain is cut by three deep transverse gorges or gaps, 600 to 800 feet deep and almost equidistant, about four miles apart. These gorges are traversed by east flowing streams which follow along the west slope from north and south, meeting at entrance of the gorge and form tributaries of Patterson Creek, which follows the valley between the New Creek and Patterson Creek Mountains. The transverse valley just north of the Grant county line, has been cut down only 100 to 300 feet, and the waters flow east and west from its central divide, while further north in the more shallow gorges the streams flow to the west. The main ridge is cut by erosion along its slopes into a series of knobs and ridges, as Walker's ridge on the western slope, Little and Knobly Mountains on the eastern side.

The geological history of the formation of these sharp ridges with the deep gorge cross valleys is one full of interest, and is due to atmospheric disintegration and river erosion in rocks of different composition and texture, thereby resulting in diversity of form. In this connection it may be well to quote the theory of origin for these structures given by Darton and Taff in the Franklin Folio of the U. S. Geological Survey:

"The deep gorges of Greenland, Cosner and Kline gaps, cut through the mountains at right angles to the general

valley system, are features of topography characteristic of this region. These gaps have been sawed by the streams which flow through them. Before any of the non-existing valleys had been cut out, a plain extended over the county east of the Allegheny Front above the top of the present New Creek and Patterson Creek mountains. The hard sandstones of the mountains were then buried beneath shales, which still extend upward on each side of New Creek and Patterson Creek Mountains, and which then filled the valleys from crest to crest of the mountains. The altitude of the plain above the sea was low. The whole region was elevated gradually to its present height, and as it rose the streams carved out and widened their valleys. When the hard rocks at the top of the arches in Greenland, Cosner and Kline gaps were reached they, too, were sawed down to the present depth. Valleys in soft rocks widen, but the ravines in hard sandstone remain narrow."

Near the northern line of Pendleton county, the South Branch of the Potomac cuts across the eastern ridges of the North Fork Mountain and follows a winding gorge to its junction with the North Fork. This gorge is between the main South Fork Range and Cave Mountain, a deeply dissected range which slopes down to the river just west of Petersburg. In the southern part of Grant county, between the Cave Mountain and the South Fork Mountain, low ridges 500 to 800 feet above the valley form a divide, known as Middle Mountain, between the two branches of Mill Creek, which empties into South Branch one mile east of Petersburg.

The Mill Creek valley is continued north in the southward sloping Brushy Run valley separated by a low divide of 100 feet, five miles north of Petersburg, from the northward sloping Patterson Creek valley. This creek with its source 1,200 feet, flows northeast in a meandering course 42 miles, where it empties into the North Branch of Potomac at Patterson, seven miles southeast of Cumberland, at an elevation of 570 feet, or a fall of 15 feet to the mile.

This interior valley which corresponds in position to the South Branch valley of Pendleton county, is six miles wide

on Mill Creek, south of Petersburg. The Brushy Run valley, north of town, is five miles wide and Patterson Creek is four to six miles wide with an elevation of 1,000 feet which is about the average elevation of the valley between the mountains from near the south line of Grant county to northern line. In the eastern part of Mineral county, the Patterson Creek valley is four to six miles wide, increasing to ten miles at the north.

The eastern line of Grant county is marked at the south by the crest of South Fork Mountain, and east of Petersburg and north by the crest of Patterson Creek mountain. This mountain begins at South Branch of Potomac and trends northeast, disappearing in low hills on the southeastern line of Mineral county. Just south of the South Branch it forms a rounded knob of 1,700 feet elevation. The main mountain is 25 miles long, with an elevation of 1,500 to 2,000 feet, with peaks and short ridges reaching 2,500 and 3,000 feet. Its western slope at the south is 1,200 feet in 1½ miles; at center, 950 feet in 1½ miles; at northern edge 500 feet in one mile; while its eastern slope is about 1,500 feet in five miles.

GEOLOGY AND STRUCTURE.

The rocks of Grant and Mineral counties are shales, limestones, sandstones and coal beds, grouped in the Paleozoic system and extending from the Upper Silurian into the Upper Coal Measures, with a few knobs in southwest corner capped by the Martinsburg shales of the Lower Silurian. All the area west of the crest of the Allegheny Front is composed of Carboniferous rocks, while the older formations lie to the east. The eastern valleys are cut in the Devonian shales, while the New Creek and Patterson Creek Mountain folds expose the Upper Silurian strata.

The following table, from the U. S. Geological Survey, Piedmont Folio, by Darton and Taff, shows the order of the formations and thickness as exposed in Grant and Mineral counties:

Period.	Formations.	Names Used by U. S. Geological Survey.	Thickness in Feet.
Carboniferous.	Monongahela series..	Elkgarden formation....	280
	Conemaugh series....	Fairfax formation.......	300
	Allegheny series......	Bayard formation.......	400 to 475
	Pottsville series......	Savage formation.....	130 to 160
		Blackwater formation.	260 to 645
	Mauch Chunk shales..	Canaan formation.......	550 to 750
	Greenbrier limestone.	Greenbrier limestone....	200 to 450
	Pocono sandstone....	Pocono sandstone.......	30 to 80
Devonian.	Catskill	Hampshire formation....	2,000 to 2,300
	Chemung	Jennings formation.....	3,300
	Hamilton	Romney shale..........	1,100 to 1,300
	Oriskany	Monterey formation.....	215 to 300
Upper Silurian.	Lower Helderberg....	Lewiston limestone.....	850 to 1,530
	Clinton	Rockwood formation.....	537 to 770
	Medina	Cacapon sandstone.....	300
		Tuscarora quartzite....	480
		Juniata formation.....	750

The description of the rocks in these different formations has been given in the chapter on Pendleton county, and the account of the strata associated with the ore deposits in that county will apply to these counties, while the higher formations of the Carboniferous have little or no application to the ore study.

The Medina sandstones and shales are exposed along the crest of New Creek Mountain and in its transverse gorges or gaps, forming in these gaps broad arches which are striking scenic features in this mountain. Outcropping on each side of the Medina in the New Creek Mountain is the Clinton formation (Rockwood of U. S. G. S.) forming narrow belts the entire length of the mountain, and it also forms, according to Darton and Taff, two small areas in Patterson Creek Mountain just east of Williamsport. These authors, in the Piedmont Folio of the U. S. Geological Survey, give the following description of the Clinton in the New Creek Mountain:

"The formation extends in a narrow belt along both sides of New Creek Mountain, lying mainly in the valley

between the main mountain and the ranges of foot-hill ridges. In Patterson Creek Mountain it is exposed in small areas, east and south of Williamsport. The finest cross-section exposure of fresh beds is in the eastern side of Cosner Gap, where 530 feet were found. They here consist of purplish shales at the bottom, with a few thin sandy beds, green and purplish shales with thin sandy layers, gray shales with sandy layers, gray shales with thin limestone layers, and the top member of 15 feet of gray massive sandstone. In most exposures the shales are weathered to a gray or gray-buff color. To the northward they appear to thicken to at least 750 feet. Iron ore occurs in most localities as two thin beds in or near the middle of the formation, but no great thickness was observed, and the ore was in greater part too sandy to be of much value. The limestone beds are mostly thin, but they are usually quite pure. They contain abundant fossils of a mixed Clinton and Niagara fauna. The gray sandstone beds which cap the formation are of general occurrence, and often give rise to a small ridge or escarpment. This sandstone is exposed in Patterson Creek Mountain in a small area east of Lahmansville, and in three depressions in the center of the mountain east of Williamsport. In the two larger of these depressions a portion of the underlying shales is also exposed."

The Lower Helderberg limestone (Lewiston of U. S. G. S.) is found along the lower slopes of New Creek Mountain, and forms most of the exposed rocks of Patterson Creek Mountain. The upper portion is cherty and the lower ledges are massive and locally called the cement beds, since this portion of the Helderberg forms the natural cement rock near Cumberland and other areas at the north.

Darton and Taff, in the Piedmont Folio, described the basal series of the Helderberg as consisting of alternations of calcareous shales and thin bedded limestones, and describes the upper portion as follows: "The basal series merge upward into the flaggy limestone series, and thin partings of calcareous shales extend for some distance into the predominantly flaggy limestone beds. These flaggy beds are quite

pure limestones, dark on fresh fracture, but weathering light-colored on exposure. They are mainly in thin beds from a half inch to two inches thick, with smooth planes along which the beds readily separate. They thicken to the east and south and attain a thickness of nearly 1,000 feet in Patterson Creek Mountain. There they rise in high ridges along the center of the mountain over an area which extends from Charles Knob to beyond Williamsport.

The Oriskany sandstone of white to rusty-brown color, with fossil casts, is found along the slopes of New Creek and Patterson Creek Mountains, the entire length. According to Darton and Taff, "the formation varies in thickness from 215 to 300 feet, with a fairly constant increase to the south and east, as is the case with the underlying cherty limestone. It is extensively exposed in the many gaps through the flanking ridges of New Creek and Patterson Creek Mountains, but the most notable exposures are in the Greenland, Cosner, Kline, Antioch and Robinson gaps, and near Seymourville and Williamsport. In the gaps it gives rise to very narrow gorges, and in most cases the waters fall over its edge."

Above the Oriskany sandstone are found the Devonian shales, dark in color weathering buff, and containing sandstone layers. These shales form the surface rocks on the lower slopes of the mountain and in the valley. The streams have cut deeply into them at many places, and county roads show high banks of these finely laminated and often crumbled shale. They are subdivided into the Hamilton, Chemung and Catskill. Above the shales come the strata of the Carboniferous exposed over the western portion of the counties.

Structure. The structure of this mountain area with its valleys is shown in the following section (Fig. 7) at the south, as given by N. H. Darton in the Franklin Folio of the U. S. Geological Survey:

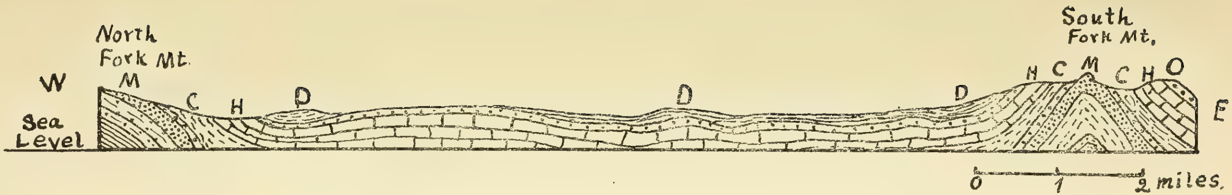

Fig 7. Geological Section across Southern Portion of Grant County (from U. S. G. S., Franklin Folio).

D. Devonian shale. C. Clinton.
O. Oriskany sandstone. M. Medina.
H. Helderberg limestone.

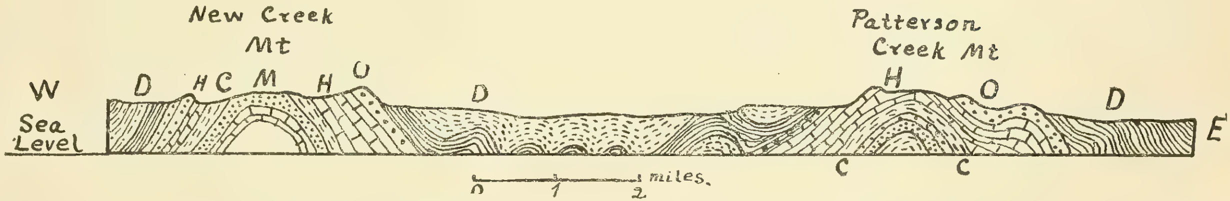

Fig. 8. Geological Section near Center Grant County (from U. S. G. S., Piedmont Folio).

D. Devonian shale. C. Clinton.
O. Oriskany sandstone. M. Medina.
H. Helderberg limestone.

The valley region is shown as a gently undulating area rising at the west in the anticlinal fold of the North Fork Mountain and east in the steep anticline of the South Fork Mountain.

The above section (Fig. 8) of Darton and Taff, in the Piedmont Folio, shows the structure across the center of Grant county, with the single anticlinal folds of the New Creek and Patterson Creek Mountains, and the crumpled shales of the valley region:

The structure of the area is described as follows by Darton and Taff in the Piedmont Folio (U. S. Geol. Sur.): "East of the Allegheny Front there rises a steep-sided anticlinal fold which brings to the surface the Upper Silurian formations in New Creek Mountain. Its axis lies at the center of this mountain, about three miles east of the front, and it extends across the area from north-northeast to south-southwest. It is a relatively simple flexure with considerable uniformity of pitch and dip. * * * * * * * In the center of the mountain the anticlinal is not flexed by minor crenulations, but rises in a mighty arch, which is superbly exhibited by the Tuscarora quartzite in Greenland, Cosner and Kline Gaps. The great sheet of quartzite springs up steeply at either side and then bends over to form a complete arch, the top of which is about 1,000 feet above the bottom of gorges. The arch is not perfectly symmetrical, for the dips on either side are not the same, and there is considerable local variation in the form of the flexure. Usually the western limb is considerably steeper than the eastern, notably at Kline Gap and southward, where the dips to the west are nearly vertical. * * * *

"Lying east of the anticline of New Creek Mountain is a wide synclinal trough containing a considerable thickness of Jennings (Chemung) formation in its center. It is quite uniform in general width, pitch and dips, but some of the beds which it contains present many minor crumples of local extent. * * * *

"The next flexure to the east is the wide corrugated anticline of Patterson Creek Mountain, which brings to the sur-

face the Monterey, Lewiston and Rockwood formations, in a range of high, knobly hills. The central axis of this flexure rises rapidly from the South Branch valley just east of Petersburg, attains its culmination from opposite Seymourville to Williamsport, and then pitches downward to the north. Along its sides it carries a number of small corrugations of variable size and extent. They give rise to ridges of Monterey (Oriskany) sandstone which, in most cases, eventually join the main mountain mass, but are separated for some distance by shallow basins of Romney (Hamilton) shales. The principal ridges of this character are the two which cross the South Branch east of Petersburg, one east of Kissell, another east of Seymourville and another extending from south of Medley to Williamsport."

Bibliography. The reports of W. B. Rogers, 1835-1841, and of Maury and Fontaine in 1876, give a number of notes on these counties. Moore and Edwards, Orton and Nitze, in their railroad reports of 1890-1891, gave an account of the iron ores in Grant county. The geology, structure and resources are described in the Piedmont Folio of U. S. Geological Survey, issued in 1895, by N. H. Darton and Joseph A. Taff, under the direction of Bailey Willis. This Folio report includes the southern portion of Mineral county and most of Grant. The southern part of the latter county is included in the Franklin Folio, written by N. H. Darton. These folio reports also include topographic, geological, economic and structural maps, and they have been of the greatest service in the foregoing sections of the present report.

MINES AND PROSPECT OPENINGS.

As was stated in the previous chapter on Pendleton county, a number of prospect openings have been made in the iron ores, in the preparation of expert reports, especially those of Moore and of Nitze; but while the number of such prospects was small in Pendleton county, they are still less in Grant and Mineral.

Near Keyser and in Greenland Gap, the ores were mined many years ago. There was an old furnace just north of the

eastern entrance to Greenland Gap, on the Babb farm, known as The Fanny Furnace, but its work closed 60 or 70 years ago, and a pile of stone and small portion of a dismantled stack, with large slag piles, are all that now mark its site. The ore for this furnace was largely gathered in form of loose boulders of brown hematite along the eastern slope of the New Creek Mountain, and also from surface strip mines in the Clinton fossil red hematite in Greenland Gap, which are now nearly completely filled with debris. On the eastern slope of Patterson Creek Mountain, in Hardy county, an old forge was located, but the pig iron was brought from the Fanny Furnace.

The openings are so few and the ore so poorly exposed in these counties that it is impossible at the present time to judge of quantity of ore available. There is a general impression among the people that the ore deposits are of large extent and even more valuable than in Pendleton county, but this cannot now be proved. The evidence is clearly against any large deposits of good Clinton ore except in the southern part of Grant county, and possibly near Keyser. The indications are good for considerable deposits of Oriskany ores, but the evidence is too scattered and too indefinite to draw any safe conclusions. It is even more true in Grant and Mineral counties than in Pendleton that a large amount of prospecting work must be done before the value of the counties in iron ore resources can be determined. The prospect openings and ore indications will now be described.

RED FOSSIL HEMATITE (CLINTON ORE).

Ketterman Prospect. In the southeastern portion of Grant county, in the South Fork Mountain, the Clinton ore is found on the summit of the mountain just west of the Hardy-Grant county line on the Adam Ketterman land. This location is 6½ miles southeast of Petersburg or 11 miles by road, and is 1,250 feet above level of the town.

A short tunnel was driven into the hill below the road to a distance of 12 feet and eight feet deep, reaching the ore at the end. It is covered by buff shales with a few sand-

stone layers. The ore vein is 30 inches thick, dipping N. 40° W. The ore is red to reddish brown, scaly in texture, with a few small fossil casts. A trench two feet deep was opened to north of the tunnel, but apparently was not deep enough to strike the ore body, at least no ore is found in it at its present depth.

On the hill above the road, 30 feet above the tunnel a number of pits were opened which struck a thin seam of red hematite ore, 6 or 8 inches thick. An analysis of an average lot of ore found in the tunnel was made in the Survey laboratory with the following results:

	Per Cent.
Metallic iron	56.00
Moisture	0.60
Loss on ignition	3.44
Silica	6.81
Iron oxide	80.00
Lime oxide	1.64
Manganese dioxide	0.04
Sulphur	0.002
Phosphorus	0.46
Titanium oxide	0.07

This area of Clinton formation, according to the map of Mr. Darton, in the Franklin Folio (U. S. G. S.), varies in width from ⅛ to ⅞ mile and 5 miles long in Grant and Hardy counties. The area included in Grant county is ¼ by 1½ miles, but the ore has only been opened at this one place.

In the southwestern portion of Grant county, Nitze reports the fossil hematite about 11 miles north of Pendleton county line on the Shreve land near Smoke Hole settlement on the waters of the South Branch, but states the indications were meager, consisting of small blocks not over two inches thick, at elevation of 1,950 feet above sea.

The Clinton formation extends along both slopes of New Creek Mountain entirely across the county in narrow belts. Blocks of ore are reported from numerous points along these lines, but the ore is more or less sandy and the deposit is apparently thin. Nitze reports surface indications in Kline's Gap of sandy shaly ore, especially on the Isaac Conrad land.

Greenland Gap. The Clinton red fossil hematite was worked for the old Fanny Furnace in surface mines just south of the road in Greenland Gap, on the Isaac Lewis farm. This place is little over one-half mile from east entrance of the Gap and 7½ miles air line distance northeast of Petersburg. The old openings follow a northeast-southwest line for a distance of one-half or three-fourths mile, but these have long since caved and become filled with waste.

At one point a short entry was driven into the east bank of the ridge, and is partly filled with water. The rocks in the entry dip 30° in a direction S. 40° E. and the entry is driven along the dip 15 feet long and 7 feet wide. At the entrance the following strata are exposed:

	Feet.	Inches.
Shales	10+	..
Red hematite	....	4
Red sandstone	4	..
Limestone	2	..
Shales	3	..

As the vein is followed in the entry it increases in thickness to 10 inches and dips under the water where it is claimed to reach 18 inches. The ore is reported as 18 to 20 inches in the old pits, but this measurement could not be verified. The ore is of good weight, brownish red in color, and apparently sandy. It has lost the scaly texture so characteristic of this ore in the southern part of Grant county and in Pendleton. It is finely granular and in some samples, oolitic. It contains numerous fossils, many of which still retain the white lime shells.

To the north of the county road, in the Creek valley, the fossil ore again outcrops about one-half mile north of the entry described above. It is 10 to 12 inches thick and dips 12 to 16° S., 50° E. Limestone is found above and below the ore. The upper limestone is 12 to 18 inches thick and over it come the Clinton shales. The ore is fossiliferous and sandy and trends N. 40° E.

The ore from the entry and from the old dumps was sampled and analyzed in the Survey laboratory with the following results:

	Greenland Gap.	Feaster Tract.
Metallic iron	42.83	41.55
Moisture	0.27	1.18
Loss on ignition	9.56	5.18
Silica	13.18	22.74
Iron oxide	61.06	59.36
Lime oxide	4.03	1.32
Manganese dioxide	0.02	0.026
Sulphur	0.04	0.02
Phosphorus	0.72	0.59
Titanium oxide	0.14	0.25

Feaster Prospect. On the eastern slope of Walker's Ridge, on the Feaster land, two miles south of the western entrance to Greenland Gap and on the western slope of New Creek Mountain, an opening was made in the hill across a small creek or run and struck the red hematite ore. It is granular in texture, sandy, with reddish brown color.

The ore bed runs N. 40° E. and dips 38° S., 40° E. It lies in buff, flaky shales and is nearly 2 feet wide. The ore was opened in a trench across the bed. At the bottom of the sloping hill, 30 feet lower, is a bed of red ore one foot thick of red hematite with direction N. 40° E. and dip of 30° S., 50° E. This exposure is in the side of the creek bank and shows the following strata:

	Feet.	Inches.
Black shales	4+	..
Red fossil hematite	1	..
Thin flaky black shale	...	4
Limestone	...	2
Shales with lime layers	1 (to water level).	

This red ore varies in thickness in the bank, and at one place reaches 3 feet. It is similar in appearance to the upper bed and with practically same trend and dip. It probably represents the same bed, as it lies in the line of direction of the dip and about the angle of slope of hill. The analysis was made in the Survey laboratory of an average sample from the upper opening.

Cosner Gap. On the John Trenton farm, in Cosner Gap, one mile west of Maysville, the Clinton red hematite is exposed at the north side of the road just beyond a small creek from the north. It here appears included in a limestone

bed, and the bed is 8 inches thick with limestone above and below. In places the ore extends into the limestone, forming a mixture of ore and limestone which is 2 feet wide. Farther along the road, the upper wall of limestone is separated from the ore and limestone mixture by 10 inches of shale, and flaky buff shales are found below the ore. The bed dips 30° S., 50° E. Six feet higher, a second iron bed is found, but it contains more lime, and trends N. 40° E. The ores at this exposure are high in lime and mixed with the limestone and are clearly due to replacement of the limestone by ore. They cannot be regarded as of economic importance.

Kline Gap. On the Trenton farm, in Kline Gap, four miles southwest of the last described exposure, and about 1½ miles east of the west entrance of the gap, the Clinton formation is found in an outcrop of limestone with thin red ore seams. The trend is N. 40° E. and dip of 40° S., 40° E. The mixed ore and limestone bed is 18 inches wide, and is enclosed in blue to black shales with limestone above.

Resume. The best exposures of the Clinton ore in the New Creek Mountain, were found in the vicinity of Greenland Gap, on the Lewis farm and the Feaster farm, where the bed was 18 to 20 inches in thickness with a local maximum of 3 feet. North of this line the ore has not been opened nor examined, and whether the ore will prove better in this direction than to the south is as yet doubtful and a number of prospect holes would be required to solve this problem.

The Clinton ores in the New Creek Mountain in all the localities examined showed a granular texture, in contrast with the scaly texture to the south. They also appear to be higher in lime and are sandy. The beds are usually thin and they apparently run quite uneven in thickness. In the Patterson Cheek Mountain none of the ore was found, and if present would be very small in quantity, as the only outcrops of the Clinton formation are two small areas southeast at Williamsport.

All of the evidence so far available apparently shows that the Clinton fossil red hematite, so far as exposed, is of little economic value in Grant county, except at the south,

in South Fork Mountain. In the North Fork Mountain, Nitze found the ore thin and not very promising. The area of Clinton ore in South Fork Mountain, in Grant county, is very small, but with a possibility of considerable extension of the ore bed over the line in Hardy county. The northern portion of the New Creek Mountain represents an unknown quantity, and until carefully opened by prospects, will have to be regarded as doubtful.

Mineral County.

In Mineral county, the Clinton red hematite ore is found with exceptional thickness, but the quality is not as high as further south. It has only been opened near Keyser, on the Alkire farm, but its outcrop can be followed to the southwest in the New Creek Mountain.

Alkire Mine. The Clinton fossil red hematite is found on the Alkire farm, one mile southeast of Keyser, in Mineral county, and it was here mined on a small scale a number of years ago. The ore is red or reddish brown in color, granular in texture, and in many specimens oolitic. Over the ore is a mass of flaky buff shales and similar shales are found below the ore which are ripple marked. The bed dips 22° in a direction N. 50° W. It breaks into oblong or nearly square blocks with the joint planes N. 40° W. and N. 30° E., and splits easily into thin flaggy blocks. The trend of the ore body is N. 30° to 40° E.

The ore was opened by trenches and one shaft, all of which are now nearly filled with loose rock. At one place a vertical measurement of five feet was made on the bed, and in the U. S. Census report of 1880 the thickness is given as 8 feet with the following composition of a sample taken across the bed:

	Per Cent.
Metallic iron	29.65
Phosphorus	0.218

This vein of ore, which is very sandy, can be followed in interrupted exposures to the north, and at least six or

seven miles southwest of Keyser, the ore outcrops along the country road, 3 to 4 feet thick and in one place 7 feet. The blocks broken from the bed by weathering have been collected and used in the construction of a stone fence at the side of the road. This outcrop can be followed almost without break for nearly a mile, and is in the buff flaky shales with a six to eight inch stratum of hard, brown sandstone over the ore. There is a large quantity of this ore with greater thickness than observed at any other place in the state, but it is very sandy and not very high in metallic iron.

The following analyses were made of the ore in the Survey laboratory. The first sample was taken from the Alkire farm, near Keyser, and the second from the outcrop along the county road northeast of Rees Tannery. They represent the character of the ore in the northern portion of the New Creek Mountain:

	Alkire Farm.	County Road.
Metallic iron	27.24	32.65
Moisture	0.10	0.25
Loss on ignition	1.17	1.50
Silica	54.30	48.88
Iron oxide	38.88	46.64
Lime oxide	0.60	0.16
Manganese dioxide	None	0.03
Sulphur	0.01	0.004
Phosphorus	0.41	0.19
Titanium oxide	0.21	0.21

BROWN HEMATITE, ORISKANY ORES.

No openings have been found in the Oriskany ores in Grant or Mineral counties in the course of the present work. Openings have been made, according to various reports, but their location could not be determined. The brown hematite or limonite ores, as reported at a number of places, when visited, were found to be merely loose boulders over the surface of the ground. Along the eastern slope of the New Creek Mountain these boulders are seen, especially in the vicinity of Greenland Gap. The boulders occur in considerable number and appear to be of good ore, but the bed was not found in place. Blocks of the same kind of ore are found on both slopes of Patterson Creek Mountain.

From the character of these ore blocks and their number at places where they are found, there is probably a valuable deposit of brown hematite ore, but it is impossible to determine how extensive the deposits may be. If the bed extends along the line of contact of the Oriskany sandstone and the Helderberg limestone, there would be a large tonnage of available ore.

As stated under the discussion of these ores in Pendleton county, the brown hematite has not attracted the attention it deserves. The Oriskany ores have been looked upon as a minor feature in the iron ore resources of the counties, while the great probability is that they represent the most important group of iron ores in the counties. The real wealth in iron will not be known until much more prospect work is done, and future exploration should be directed to these Oriskany ores.

With the present limited knowledge of the extent and thickness of the Grant county and Mineral county ores, it would be of little or no value to attempt any estimates on tonnage. There is the possibility of sufficient quantity of ore to pay for their development and this should be tested by most careful prospect work carried out in a practical and systematic manner. The nearness to the coal fields and the few difficulties in reaching the ores by railroad construction afford valuable conditions for ore development in these counties, if the ore is present in sufficient quantity. These two counties have long been looked upon as valuable iron ore counties, and it is hoped that some company with sufficient capital will investigate the conditions and secure adequate proof for or against the existence of these ores in commercial quantity.

CHAPTER VIII.

THE IRON ORES IN HARDY AND HAMPSHIRE COUNTIES.

GEOGRAPHY OF HARDY AND HAMPSHIRE COUNTIES.

Hardy county, located next to the Virginia line in the eastern mountain belt of West Virginia, was formed in 1786 from portion of Hampshire county and named in honor of Samuel Hardy, a member of Congress from Virginia. Its area is 594 square miles,[1] with a population of 8,449, and county seat located at Moorefield, in southwestern part of the county. The mean annual rainfall is 50 to 60 inches, and the mean annual temperature 45° to 50°. The elevation ranges from 800 to 3,000 feet.

The county is bounded on the north by Hampshire county; on the west by Grant; on the south by Grant, Pendleton and Rockingham county, Virginia; on the east by Shenandoah and Frederick counties, Virginia. There is not a mile of railroad in the county. Wardensville, in the eastern part of the county, is reached by daily mail but not by stage. It can be reached by 30 mile drive from Winchester, on the Shenandoah branch of Baltimore and Ohio railroad, or 24 miles from Capon Road on the same railroad.

Moorefield, the county seat, is reached by daily stage from Romney and also connects with stage from Keyser. The distance from Keyser is 35 miles, and from Baltimore and Ohio Railroad at Romney 28 miles. Moorefield is the largest town in the county, with a population of 495, while Wardensville has 300. Both of these towns have general stores, good hotels and livery, and are central points for the

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[1] Statistics in these sections from U. S. Geological Survey, Bull. 233, Gazeteer of West Virginia.

study of the iron ores in eastern and western parts of the county. Moorefield is 10 miles from north line of the county, and 15 miles from south line, or 21½ miles from the extreme southwestern end. It is 5 miles from west county line and 23 miles from east line. The distance by road from Moorefield to Wardensville, almost due east, is 32 miles.

Hampshire county, located north of Hardy, is the oldest county in the state, formed in 1754 from parts of Frederick and Augusta counties, and named from Hampshire, England. Its area is 662 square miles, population 11,806 and county seat at Romney, in western central portion of the county. The mean annual rainfall is 50 to 60 inches, and mean annual temperature 45° to 50°, with average elevation about 1,000 feet.

The county is bounded on north by Morgan and by Allegheny county, Maryland; on west by Mineral county; on south by Hardy; and on east by Frederick county, Virginia. The Baltimore and Ohio railroad follows its northern edge, a distance of 16 miles, with a branch 16 miles long south to Romney, a town of 500 people, which is a central business point to the whole district of Hampshire and western Hardy counties.

TOPOGRAPHY OF HARDY AND HAMPSHIRE COUNTIES.

Like the other mountain counties, Hardy and Hampshire are crossed by northeast-southwest mountain ranges and valleys. Hardy county extends along its southwest line to the crest of the South Fork mountain for a distance of 9 miles where the boundary bends to the west 7 miles to Patterson Creek mountain, and follows this to north line of the county.

The South Fork mountain extends northward to within 3 miles of Moorefield, and is locally called in Hardy county, Middle Mountain. It varies in height from 3,000 feet at the south to 1,300 and 2,000 feet at its northern end. Its slopes are deeply cut by ravines and the western slope is very steep. At the northern end it slopes from 2,200 feet to 900 feet at the South Fork river in a distance of 2½ miles. Patterson

Creek mountain along the Hardy line is 2,500 and 3,000 feet and the valley to the east is 800 feet, or a slope of 1,700 feet in 4 miles, 425 feet to the mile. This mountain is cut by the narrow valley of the South Branch through which the county road passes from Moorefield to Petersburg, 11 miles distant. Patterson Creek mountain forms the western line of Hampshire county for 9 miles north where it disappears as a mountain ridge, and is continued northeast along the county line in form of low hills and ridges reaching a height of 1,700 feet.

East of Patterson Creek mountain in northern portion of Hardy and across Hampshire county is the Mill Creek mountain extending northeast 20 miles to four miles north of Romney where it is cut by the South Branch valley, and then continues northeast to the Potomac. Its crest is 1,700 to 2,000 feet above sea level with High Knob 2,600 feet on the Hardy-Hampshire line.

To the west of Mill Creek mountain is the Mill Creek valley which in Hardy county merges with the South Branch valley, one of the scenic valleys of the state with its rich and prosperous farms, locally known as the Moorefield Valley. There are few places in the state, where farm lands so far distant from railroad command the high prices of farms in this valley. The South Branch valley is 6 to 8 miles wide near Moorefield with an elevation of 800 to 1,000 feet.

From southern end of Mill Creek mountain, north seven miles the South Branch river follows a deep and narrow gorge in the mountain parallel to its trend, then widens out into a valley about 3 miles wide to Romney. The county road from Moorefield to Romney leaves the South Branch valley at Mill Creek mountain and follows the broad Mill Creek valley at the west passing through a gap in the mountain near Romney back to the South Branch.

The South Fork river from Pendleton county passes through a narrow valley in southern Hardy county between the Middle mountain and the South Branch mountain until it comes into the South Branch valley 2½ miles south of Moorefield and empties into the South Branch at Moorefield. The South Branch river has an elevation of 800 feet at Moore-

field and 700 feet two miles north of Romney a distance of 25 miles or a fall of 4 feet to the mile. It then changes from its nearly straight course to a meandering channel reaching the Potomac about the center of the north boundary line of Hampshire county at an elevation of 540 feet, a distance of 38 miles or a fall from Romney to mouth of 4 feet to the mile.

The South Branch mountain through Hardy and into Hampshire county is 30 to 35 miles long with an elevation of 2,500 to 3,000 feet, with steep slope to the west and more gradual one to the east. It is deeply cut by transverse gorges and on the eastern slope is broken into minor short ridges.

In the eastern portion of Hardy and Hampshire counties, there is a marked contrast in the arrangement of stream valleys. In the latter county these maintain their northeast more or less parallel directions, but in Hardy county while many of the streams follow this course, there is a marked development of east and west narrow valleys breaking the mountains into short ridges.

The Cacapon river empties into the Potomac in Morgan county, nine miles west of Hancock, and follows a very winding channel often between high and nearly vertical cliffs from the Forks of Cacapon six miles south of the Morgan-Hampshire county line. It is here joined by the North river. The Cacapon river two miles west of Wardensville passes through a natural tunnel in Sandy Ridge, through the Lower Helderberg limestone, though an old channel passes around the north end of this ridge. West of this tunnel it is known as Lost river.

Lost river has its source in the southern part of Hardy county and flows northeast to Baker's run, being joined by numerous tributary streams. It then flows eastward across the mountains to Wardensville and from this point northeast again to Forks of Cacapon, the name of the river changing to Cacapon when it emerges from the Sandy Ridge tunnel. The elevation at the source is 1,800 feet, and 1,100 feet at Wardensville or a fall of 20 feet to the mile for the 35 miles distance. Its elevation at Forks Cacapon is 600 feet or fall of 15 feet to the mile in the 34 miles from

Wardensville. From this point to the mouth is 36 miles where elevation is 430 feet, or a fall of 5 feet to the mile.

The Lost River valley is one to two miles wide with an elevation of 1,500 to 1,700 feet and is bounded on the west by the South Branch mountain and its minor ridges; and on the east by the Cove mountains, which are foot hills of the Great North mountain. These ridges are almost level topped with an elevation of 2,500 to 2,700 feet, and are separated by the coves or water gaps.

The Cacapon River valley at Wardensville is about 4 miles wide with elevation of 1,100 to 1,400 feet, with the river nearly in center of the valley. At Capon Bridge, Hampshire county, the valley is one mile to one and a half miles wide, with the river against the west mountain ridge. At the Forks of Cacapon the river follows the east ridge and is two miles wide but is a narrow gorge south for two miles.

Two tributary streams to the Cacapon near Wardensville form well defined but narrow southwest valleys. Waites Run to the east of town has its source in the North Mountain and passes through a deep gorge in this mountain. To the west of town is Trout Run with its tributary stream, Thorny Bottom with valleys one mile in width.

The North River rises on the eastern slope of the South Branch mountain and flows eastward through northern portion of Hardy county through a gorge in Short mountain, and near the north county line bends northeast to the Forks of Cacapon where it joins the Cacapon river. Its valley is two to six miles wide in Hampshire county with an elevation of 1,000 to 1,400 feet above sea. The level at its source is 1,900 feet and at its mouth 600 feet, with a length of 44 miles or a fall of 30 feet to the mile.

In central and northern portion of Hampshire county betwen the Cacapon and South Branch rivers is the Little Cacapon river following a parallel valley which is separated from the other valleys by low divides or short ridges 1,500 feet in height.

The eastern border of the county is on the crest of Great North mountain with elevation of 2,500 to 3,000 feet with

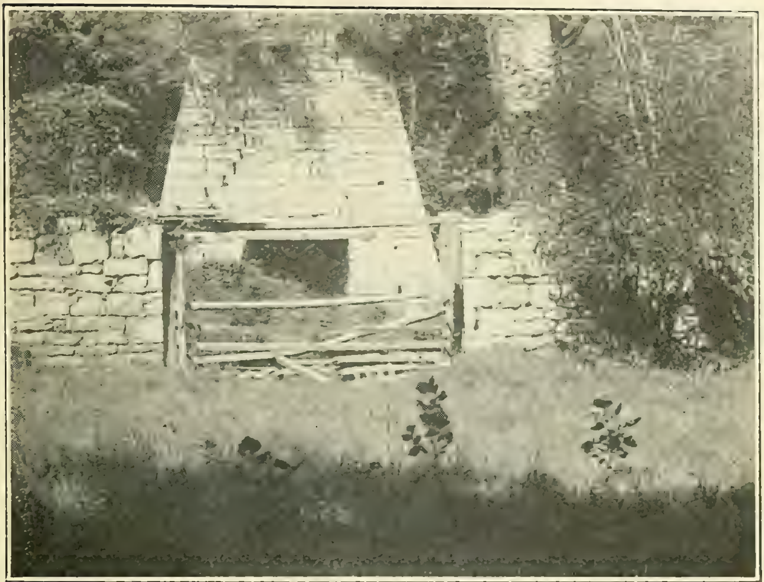

Plate IV.—A.—Capon Furnace Stack near Wardensville, Hardy County.

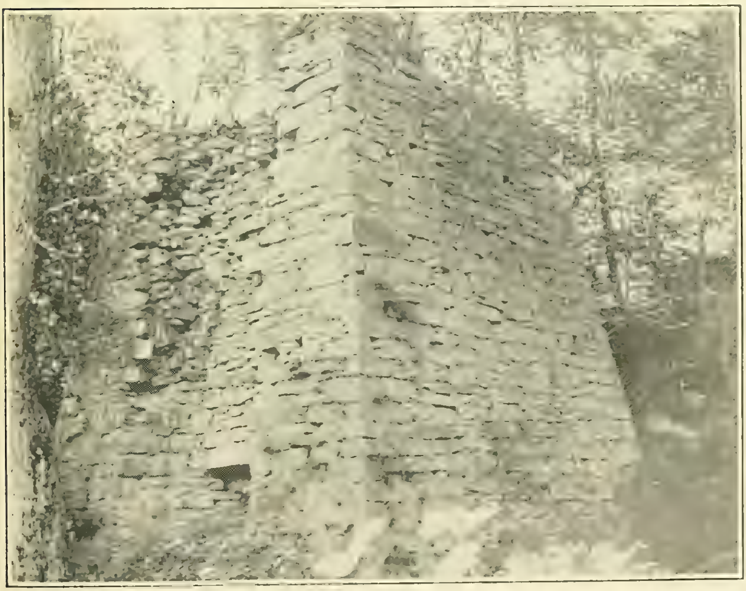

Plate IV.—B.—Crack Whip Furnace on Trout Run, Hardy County.

few peaks 3,200 feet. The slope from crest to Wardensville is 1,300 feet in 3 miles or 430 feet to the mile. At the south to Trout run the slope is 1,200 feet in distance one mile. The eastern boundary of Hampshire is an irregular line to west of the North Mountain on a low ridge 800 to 900 feet, and at northeast the Cacapon mountain 2,000 feet high forms the boundary.

GEOLOGY AND STRUCTURE.

The rocks of Hardy and Hampshire counties consisting of shales, limestones, and sandstones, belong in the Paleozoic system and extend from the Silurian into the Devonian. The order of arrangement is given in the preceding chapter. There has been no detailed examination of the geology of these counties, and in the present work, attention was given only to the rocks directly associated with the ore deposits.

The valleys are cut into the Devonian shales, which are especially well exposed in the South Branch valley. The South Branch mountain exposes the rocks from Hamilton shales to the Lower Helderberg limestone. The Oriskany sandstone, Clinton and Medina formations are exposed in Middle Mountain. The Lost River valley is cut into the Lower Helderberg limestone at Sandy Ridge and further east in the Devonian shales. The tops of the ridges in the Trout run valley are capped by the Oriskany and the Helderberg, while the North Mountain exposes on its slopes and its crest the Medina and Clinton formations. The rock characters are similar to those described in the other counties.

The structure of the ranges and valleys to west of North Mountain is a series of eroded anticlines and synclines, much crumpled at the east and in North Mountain, thus bringing the lower formations on the lower slopes and on the crest, resulting in a complicated structure which is obscured by surface covering of rock debris and heavy forest growth. This structure is shown in Rogers section reproduced in

figure 9. These mountains contain a large quantity of timber which is one of the very valuable assets of the area.

Bibliography. W. B. Rogers in his Geological Reports 1835-1841 gives a number of notes on this area and includes a number of cross section structural profiles. Maury and Fontaine in 1876 include in the Centennial report an account of the iron ores. In 1906 the writer made a report on the iron ores in the eastern part of Hardy and southeastern portion of Hampshire county, for eastern parties who have kindly given permission to use these notes and analyses in the present report. Mr. John Fulton in 1880 made an expert report on the ores in the Moorefield region.

MINES AND PROSPECT OPENINGS.

In the Moorefield area a number of prospect openings were made 20 or 30 years ago and an incorporated iron company organized at that time still controls the ore lands on Middle Mountain. In the Upper Lost River valley some attention has been paid to these ores, but very few openings have been made. In the Wardensville area, three furnaces were formerly in operation, two of which are standing. To supply these plants numerous mines were opened and prospect pits were made in all directions so that more exposures of the ore are found than any other section of the state. The last furnace run was made in 1882, over 25 years ago, and in that time the shafts have caved or filled with water, the old tunnels and entries have fallen shut, and the sides have caved in the open cuts. When these pits were examined in 1906 very little of the ore could be examined ,but during the past year many of these places were reopened and new openings were made which permitted more complete examination. All of these recent openings are shallow, work being stopped in most cases when the ore was struck. No drilling has been done so that the depth cannot be determined. It is very probable that more extensive work and deep drillings will be made in the near future as the property is under option.

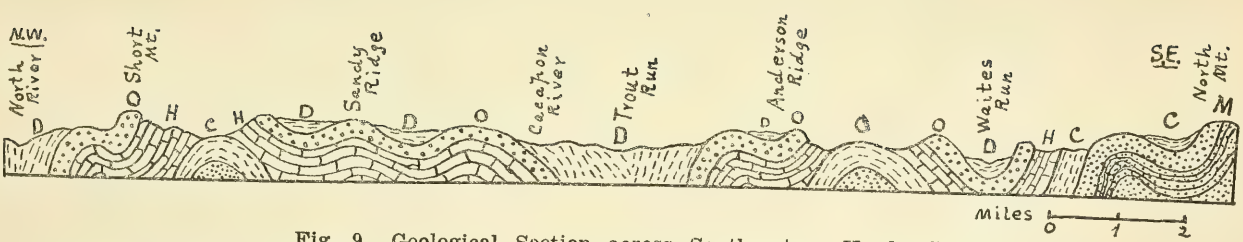

Fig. 9. Geological Section across Southeastern Hardy County (after Rogers).

D. Hamilton Shale.
O. Oriskany sandstone.
H. Helderberg limestone.
C. Clinton.
M. Medina.

This North Mountain ore belt has been followed northward into the southern part of Hampshire county, but with no openings into the ore body. Further north at Bloomery an old furnace is standing, (See plate VI), but the ore mines were mainly shafts and tunnels which have caved. The few places in this section visited showed nothing at surface except loose boulders, and the overseer of the furnace property claimed that all of the old workings had fallen shut and that it was impossible to study the ore. The ore at the old furnace dump was sampled and showed the following composition:

	Per Cent.
Metallic iron	42.63
Moisture	0.54
Loss on ignition	7.98
Silica	25.02
Iron oxide	60.90
Lime oxide	0.45
Manganese dioxide	0.01
Sulphur	0.09
Phosphorus	0.25
Titanium oxide	0.14

According to reports of men in this region the ore bodies were scattered and very variable in grade. The ore on the dump near the furnace is honeycomb in structure and only of fair grade. It seems probable that ore of good grade is to be found, but it will require prospect work in form of excavations and drilling to prove the value of this region. The various mines and prospects will now be described.

MOOREFIELD AREA.

McMicken Prospect in Clinton Ore. On the eastern slope of Middle Mountain which is the northern portion of the South Fork mountain about 7½ miles southeast of Moorefield on the Baker land, McMicken and Co., opened a small prospect in the Clinton red fossil hematite some years ago. The location is near the head of a small ravine and on its south bank, about three-fourths mile east of the

house of John Wolff and 480 feet lower, or about 1,700 feet above sea.

The bed of red hematite dips about 16 degrees north-east. The ore breaks into blocks with joint planes N. 10° W. and east and west, and the pit shows the following strata:

	Feet.	Inches.
Shales	4	..
Brownish sandstone	6	..
Shales	1	..
Red shales	0	10
Sandy ore	0	6
Red hematite	1	2

160 feet higher is a heavy ledge of hard yellowish-white sandstone.

The ore is thus 18 inches thick and has been opened for a distance of about 20 or 30 feet and its outcrop in the form of loose blocks has been found further north. While the outcrop is of doubtful economic importance unless a larger bed is found, it is of interest as indicating the continuation of the Clinton red hematite found in the South Fork mountain in Pendleton county. Its composition is given in the following Survey analysis:

	Per Cent.
Metallic iron	**44.46**
Moisture	0.50
Loss of ignition	10.75
Silica	8.30
Iron oxide	63.52
Lime oxide	10.35
Manganese dioxide	0.035
Sulphur	0.019
Phosphorus	0.48
Titanium oxide	0.07

Burns Knob Prospect. One mile and a half southwest of the John Wolff house, 140 feet higher, on a high knob locally called Burns Knob on the Nick Baker land now owned by the Moorefield Iron Co., about 9 miles from Moorefield, openings have been made in the brown hematite.

The ore was opened by a trench 12 to 15 feet deep running east and west about 30 feet long. A second trench just to the east, almost in line with the first, is 25 feet

long. The ore opening shows 5 feet in depth but it is still in ore, so that depth is unknown. At this place the cover consists of 12 to 15 feet of shales. To the south about 400 feet is an outcrop of heavy white sandstone. Further south is a high cliff of the same sandstone rising to 115 feet above the ore in the trenches. This sandstone is a close grained white rock with no trace of fossils, representing one of the Medina sandstones, and the ore is a brown hematite in the Clinton shales and clay.

This ore is deep chocolate brown color with botryoidal surface very characteristic. The ore is coated with these raised round globular masses and pipes. The surface exposure of the ore is in boulders but becomes solid below, and is apparently very uniform in texture and quality which is of high grade. It has the following composition according to the Survey analysis:

	Burns Knob.	Fisher Farm.
Metallic iron	52.70	53.14
Moisture	0.14	0.24
Loss on ignition	9.71	10.14
Silica	13.81	10.48
Iron oxide	75.28	75.92
Lime oxide	0.22	0.46
Manganese dioxide	0.04	0.035
Sulphur	0.007	0.001
Phosphorus	0.26	0 15
Titanium oxide	0.01	0.07

John C. Fisher Farm. On Middle mountain above and to the east of the John Fisher house, seven miles southwest of Moorefield, is a second group of prospect openings in this brown hematite 500 or 600 feet above the valley.

The ore was opened in several pits and a long trench excavated in an east and west direction up the hill. The west wall is limestone which shows also to the south. The ore is associated with flint fragments in large quantity. A second trench was driven for 200 feet in a north and south direction. The width of the vein is about 14 feet as shown by these trenches. The deep trench shows ore, shale, and flint in its entire depth of 25 feet which has apparently reached the main ore body, and represents the Oriskany horizon.

The ore has a honeycomb structure with considerable dirt through it, and is light to dark brown in color.

Loose blocks of the limonite ore are found along this mountain at a number of places, but these two openings are the only prospects. There appears to be along this slope of the mountain a large body of ore which will probably be at least three miles long with an average width of 12 to 14 feet. Its depth has not been determined but from the records to the south in Virginia, it will probably reach at least 100 feet with possibility of reaching even greater depth. These figures would represent an available ore supply of 1,390,000 tons. This ore has not been reported from the western slope of this mountain, though careful prospect work may reveal its presence in that area. The above estimate is founded on uncertain data and only represents the possibility as it will require much more prospect work to finally decide the quantity of ore.

South Branch Mountain. At various points along the slopes of the South Branch mountain to the east of Moorefield, blocks of brown hematite are reported as present in considerable quantity. The ore is found in loose blocks and no prospect openings have been made to determine the exact location of the bed, but there are indications of considerable deposits of this ore. On the land of Mr. Brawl, six miles east of Moorefield, the brown hematite ore is said to occur in quantity in form of loose blocks.

On the Joseph D. Ruckman farm on the hill a quarter mile to the south of the Wardensville road, nine miles east of Moorefield the ground is covered with loose blocks of ore but no prospects have been opened to determine the ore in place. From its association it is apparently the Oriskany horizon, and the ore is of good quality, but it is impossible to determine its extent. The boulders trend along a northeast-southwest line. Further down the road the wall of light gray sandstone runs. N. 45° E. and here shows five feet of ore with the following composition:

Metallic iron	31.96
Iron oxide	45.65
Silica	34.41

The slopes of this South Fork mountain with its scattered ore blocks may prove rich in brown hematite ore, but like the localities in Grant county, it will require careful prospect work in numerous openings to prove its value in ore.

The eastern slope of Patterson Creek mountain, or as it is locally called, Orr's Mountain, shows the Oriskany-Helderberg contact, and here and there are scattered blocks of ore which would indicate ore bodies along its eastern slope in Hardy county. There is also the possibility of finding brown hematite ore deposits along the slopes of Mill Creek mountain from a point seven miles north of Moorefield to Romney in Hampshire county.

To the east of South Branch Mountain in Short Mountain, loose blocks of brown hematite ore are also reported, and an old furnace was in operation there many years ago.

When the eastern part of Hardy county with its rich ore prospect openings is compared with the evidence of ore in the western part where almost no openings have been made, there is certainly much encouragement for valuable deposits in the Moorefield vicinity, but this development work should be carried forward until there are as many openings in the ore as at the east. If the farmers would open the ore on their own lands during the spare time of the winter or other time, the careful prospect work would add to the value of their land. The people should not be satisfied to merely know that in fields and on mountain slopes they can find loose boulders of ore, thereby reaching the conclusion that whole hills of iron exist. The ore should be opened so that a possible investor can actually see the ore in place and not have to make a guess as to its existence in commercial quantity. Instances have been found where the land has been held at very high price because of these ore boulders, and where no facts were available as to real quantity or value of ore. A small body of ore will furnish a large number of boulders which may roll down a slope some distance giving the appearance of a wide deposit. In such prospect work it should be remembered

that these heavy ore boulders do not roll up hill, so in looking for their probable source the line will not be below the highest line of boulders. Again the trend of the ore bodies is almost without exception north 20° to 40° east, so a trench dug to locate the ore body should be made at right angles to this direction and carried for some distance and to some depth. When the ore body is once found then it may be followed by pits along the northeast or southwest line to determine the length. It is unfortunate that at the present time in all the Moorefield region, three or four prospect openings include all the work on these ores, when there is so much encouragement for prospect work.

LOST RIVER AREA.

Lost River post office on Lost River is 11 miles southeast of Moorefield across the South Branch mountain, or 20 miles by the road across this mountain. It is 23 miles by road southwest of Wardensville.

In the Cove Mountains to the south and east of Lost River P. O., and Methias, the slopes of the mountains show iron ore boulders over most of their distance. These are abundant on the J. Ward Wood land on Lower Cove Mountain and in the Upper Cove. The bed could not be found in place, but the number of large boulders of brown hematite would indicate an extensive deposit on both slopes of the mountain. The sides of the mountain are here thickly covered with the large boulders of Oriskany sandstone covering the ground and filling the ravines so that they can only be traversed with difficulty on foot. A careful search was made for the ore bed in a trip from the west slope across the mountain and along the sides of this mountain, but it could not be found in place. The distribution of the ore boulders shows that the outcrop is somewhere near half way up the mountain.

The composition of this float ore on the J. Ward Wood land is shown by the following Survey analysis:

	Per Cent.
Metallic iron	50.96
Moisture	0.27
Loss on ignition	8.83
Silica	12.44
Iron oxide	72.80
Lime oxide	0.40
Manganese dioxide	0.47
Sulphur	0.023
Phosphorus	0.41
Titanium oxide	0.18

Strausman Farm. About two miles east and south of J. Ward Wood's house at the foot of Cove Mountain on the Riley Strausman farm the boulders of brown hematite ore are found with limestone to the east and the Medina sandstone to west. The limestone ledges trend N. 25° to 30° E. The position of the bed can be here closely approximated from the relation of the sandstone outcrop to the limestone, and the ore boulders follow along this line but the ground is strewn with the large sandstone blocks and no openings have been made. The ore is reddish-brown in color with somewhat porous structure and near the sandstone has inclusions of sand. Fragments are found adhering to the sandstone wall. The age of the limestone is somewhat uncertain as no fossils were found and it may represent the Shenandoah limestone, making the ore Silurian probably included in the Clinton series.

Bear Wallow Ridge. To the southwest of the last on Bear Wallow on the Keller farm is a well marked ridge of brown sandstone trending N. 40° E, and dipping 30 degrees in a direction N. 50° W. and apparently forming the hanging wall of the ore. The sandstone apparently forms the crest of the ridge with the ore body passing under it, and ore is found to the east and west of this sandstone cap. The lower portion of the sandstone has ore adhering to it and penetrating it, in stringers.

From the surface exposures of the ore and the distribution of the large ore blocks, the bed is probably at least 15 feet thick, but it may be even greater. The ore is reddish brown in color, with some blocks a light brown, and contains glistening black areas. It breaks irregularly shaly, and con-

tains few cavities. Its appearance and association are similar to the ore on the Strausman farm and it doubtless represents the same bed as blocks of same kind of ore are found on the mountain between the two places. The chemical composition of the ores from the Strausman and the Bear Wallow ridge on Keller farm is shown by the following Survey analyses:

	Strausman.	Bear Wallow.
Metallic iron	39.20	44.69
Moisture	0.10	0.29
Loss on ignition	11.35	6.66
Silica	35.86	21.63
Iron oxide	56.00	63.84
Lime oxide	0.08	0.16
Manganese dioxide	0.017	0.04
Sulphur	00.000	0.02
Phosphorus	0.23	0.39
Titanium oxide	0.07	0.21

This bed was followed to the southwest over a half mile, and is found further south in an outcrop on the county road, also to the west on Saw Log ridge, and on the Big Ridge northwest of Methias. Brown hematite ores are reported on the west slope of the North Mountain to the east and southeast of Methias. This Lost River area contains a number of deposits of excellent brown hematite ores, but the ores have not been prospected and no openings have been made in them. The ravines where the outcrop should be exposed by erosion are filled with the large sandstone blocks so that in this area it is impossible to accurately estimate the tonnage. Higher on the slopes of the Cove Mountains is the compact white sandstone of the Medina, but the ore examined is below the brown sandstone. There may be a second ore body between the white and brown sandstones similar to the deposits in eastern part of the county. Indications of this ore body in form of blocks of ore were found on the J. Ward Wood farm, but along this portion of the mountain the blocks of sandstone are so numerous that very few other rocks are found.

The area well deserves exploitation and the ore bodies should be opened. Across the North Mountain in Virginia,

only a few miles distant the ores are regarded as very valuable and have long been mined for use at the Liberty Furnace. There is certainly a large deposit of brown hematite ore below the brown sandstone on the eastern slope of the Cove mountains, with a possible second important ore body above this sandstone and below the white sandstone. The lower horizon can be followed for nearly five miles, and with a width of 15 feet and an assumed depth of 75 feet, would yield 2,500,000 tons of ore.

In a farm road across the J. Ward Wood land in the Lower Cove a bed of red hematite, compact in texture was observed in buff shales with a northeast trend, but its width could not be determined. Its outcrop is claimed to be traced for a mile and was followed near the road for 300 feet. No openings have been made in it, but if it should be found wide enough for economical working would prove an important ore body.

CAPON IRON WORKS AREA NEAR WARDENSVILLE.

Three and a half miles due south of Wardensville is the old Capon Furnace owned by the Keller estate which includes about 4,000 acres and is surrounded by iron ore tracts owned by other parties. The county road follows up Waites run and is 5 miles long from Wardensville.

Capon Furnace was one of the most successful charcoal furnaces in the State and was worked almost continuously for 48 years from 1832 to 1880. (See Plate IV-a). During this time many mines and prospects were opened, but most of them had fallen shut, but in the past year, a number of these were reopened and new prospects excavated, so that conditions are more favorable for the ore study in this area than any other section north of Greenbrier County.

Pee Dee Mine. This mine was formerly used to supply ore to the Capon Furnace, but was not used during the later history of the work. It is located one mile southeast of the furnace on the western slope of North Mountain and 430 feet above the furnace level.

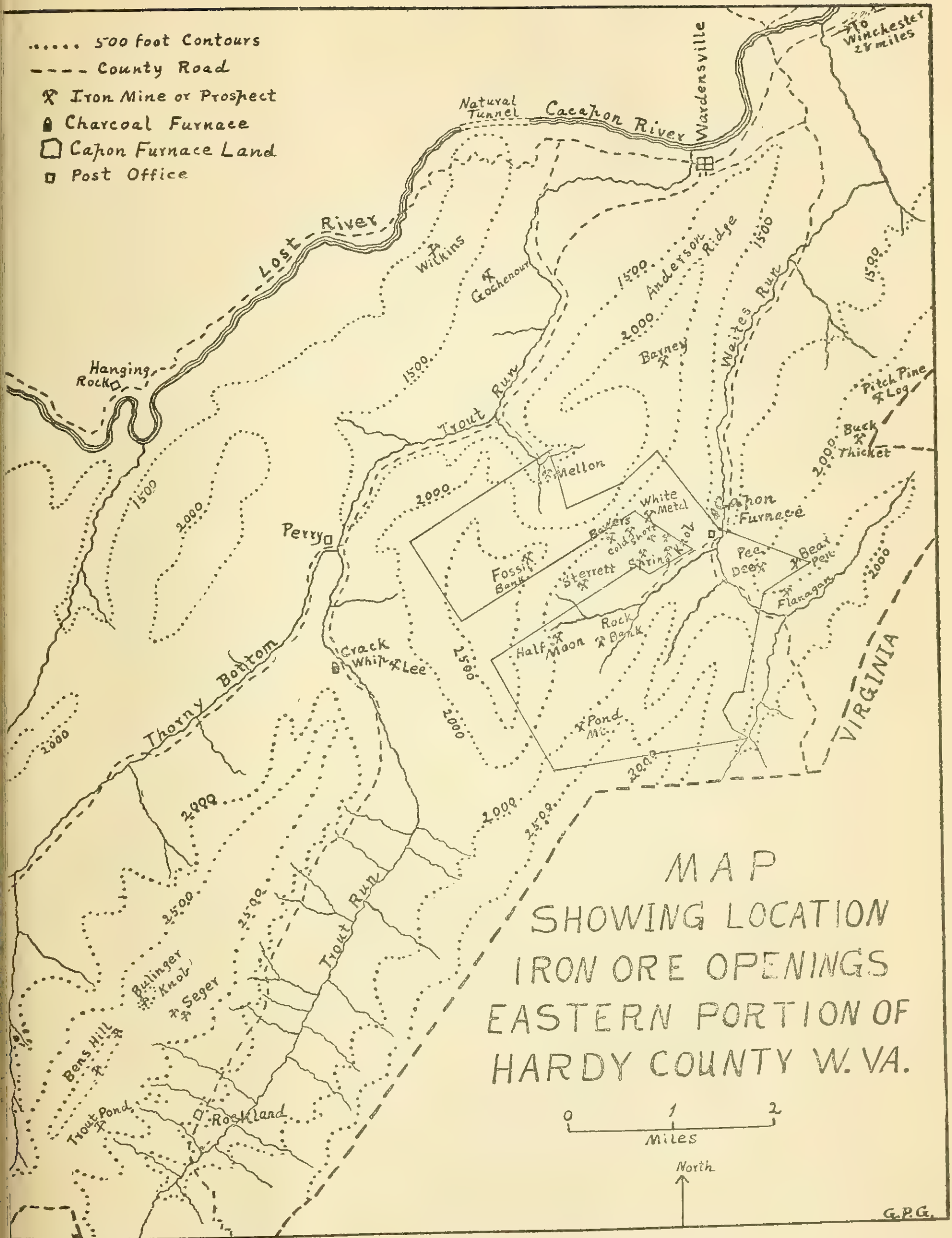

Fig. 10. Map Showing the Location of Iron Ore Mines in South-Eastern Hardy County.

The ore was mined in an open cut 125 feet long running north 30° east, also by a shaft which was sunk 43 feet deep with ore to within 8 or 10 feet of the top, and the bottom of the shaft was still in good ore according to the testimony of reliable men who worked in the mine. Later a cut 140 feet long was made at right angles (S. 38° E.) to the 125-foot trench and struck ore one-fourth of the distance. Over the ore body is a mass of buff shales exposed with a thickness of 20 feet in the trench. Above the shales is a ledge of hard white sandstone, probably the Medina, which has an exposed thickness of 25 feet. This rock dips into the mountain S. 40° E. at an angle of 28 degrees. The shales dip in the same direction 40 degrees, and the ore with an angle of 40° to 50°.

Ten feet below the ore is a brown sandstone 15 or 20 feet thick as exposed, and breaking into courses 6 or 8 inches thick. An ore body is found below this sandstone or 36 feet below the upper ore, and was opened by a number of pits in buff shales, but these are now closed.

The Pee Dee ore is deep brown in color, more or less honeycomb in structure and the holes filled with yellow ochre. In the shaft the ore is more solid with a bluish-brown cast, with some blocks deep brown to almost black and more or less porous, the lower bed of ore is a deep brown color more or less mottled with bluish-black areas. It contains wavy lines with black coating and breaks shaly. White clay is associated with both ore bodies. The surface ores to a depth of one or two feet show the effects of weathering and are light yellow-brown color, shaly, and lighter in weight than the main body of ore.

The upper trench followed nearly the trend of the ore, while the lower trench at right angles cut across the bed. The openings made show the width to be at least 20 feet and an exposed length of 125 feet, but both ends of this trench were still in the ore body. The composition of the Pee Dee ore is shown in the following analyses, the first made by Ricketts and Banks,[2] and the second in the Survey

laboratory; and the third analysis also made by the Survey shows the composition of the lower ore body:

	Ricketts and Banks.	Survey.	Lower Ore Body.
Metallic iron	48.32	47.40	47.94
Moisture	.....	0.30	0.46
Loss on ignition	.....	10.40	10.80
Silica	17.59	27.02	16.82
Iron oxide	.....	68.00	68.48
Manganese dioxide	0.06	0.66	0.02
Sulphur	0.37	0.008	0.02
Lime oxide	.....	0.10	0.24
Phosphorus	1.138	0.28	0.22
Titanium oxide	.....	0.11	0.21

These ores have generally been regarded as Oriskany ores similar to those mined in southern part of Virginia, but as described above they are found with the hard quartzose sandstone, the Medina, and in the shales on the mountain slope below this rock and above the brown sandstone. At the foot of the mountain and to southwest is a mass of bluish-gray limestone without fossils, probably the Shenandoah limestone. On the top of the mountain is the Clinton formation with red hematite, thin yellow or buff sandstones filled with Clinton fossils. The fossils were kindly examined by Mr. R. S. Bassler of the U. S. National Museum, who states that Beyrichia lata is the most characteristic fossil, and that the formation is Clinton (Rockwood).

The structure involves an overturned fold. The ore bearing shales are probably Clinton with the Medina sandstone above instead of in its proper position below. The lower bed is probably the same as the upper, with a portion of the Medina brown sandstone brought in between the two exposures.

Warm Spring Mine. About three-quarters of mile southwest of Capon Iron Works is a warm spring through which gas is constantly bubbling and which has long been

[2] The analyses of ores by Ricketts and Banks and by Mr. Glaser used in this chapter, as well as many notes included in the discussion of the ores in eastern part of Hardy county, are taken from the writer's special report on these properties for Mr. Nathan Landauer, of Baltimore, and used with his permission.

held in high esteem as a medicinal spring for the cure of rheumatism and other disorders. On the ridge about one-fourth mile west of the land of Mrs. Kline, and 200 feet above the level of Capon Iron Works is an outcrop of reddish-brown ore which has been opened in a long trench against the sandstone wall. This coarse brown sandstone pebbly or conglomeritic in places trends N. 40° to 50° E. and dips 20 degrees S. 60° E.

The ore next to this sandstone wall is broken by streaks and nodules of coarse reddish sand, but farther away appears to be free from the sand though sand particles are found in most of the ore. The ore is dark brown in color though some has a reddish-brown color and breaks shaly. This ore was tried at the furnace but was only opened to a limited extent and then abandoned, the sand streaks and particles being considered objectionable. Its composition is shown by the following Survey analysis and also by the analysis of another sample of Ricketts and Banks:

	Warm Spring Mine Ore.		
	Ricketts and Banks.	Survey.	Spring Knob Ore.
Metallic iron	52.99	55.55	40.54
Moisture	.....	0.30	0.29
Loss on ignition	.....	11.96	10.21
Silica	10.10	5.59	19.66
Iron oxide	....	79.36	57.92
Lime oxide	.....	0.20	0.25
Manganese dioxide	0.14	0.30	0.30
Sulphur	0.08	0.01	0.01
Phosphorus	0.987	1.46	1.86
Titanium oxide	.....	0.07	0.25

The ore in its relation to the brown sandstone occupies a similar position to the Pee Dee mine.

Spring Knob Mines. On the northwestern side of the hill locally known as Spring Knob on the Kline land, and 60 feet lower than the Warm Spring mine, the brown hematite ore was opened in a trench eight feet long across the ore bed which trends N. 30° E. The bed dips to the southwest with a heavy wall of brown sandstone outcropping above forming a sharp ridge, and forming the foot wall of the ore. The ore body has been worked with a length of about 300 feet.

The openings are nearly on the N. 30° to 40° E. line from the Cold Short mine, and they are located at the big bend of the tram road from the Half Moon mine to the furnace.

The ore is close grained, light brown color with small openings along parallel lines giving much of the ore a shaly appearance. Its composition is shown by the above Survey analysis.

Manganese Prospect. In the road which follows the creek at the foot of Spring Knob and about 150 feet above the level of the furnace, is a heavy deposit of yellow clay in which are veins of dark brown to black ore which is soft and brittle, trending in a direction N. 40° E. The outcrop can be followed nearly 100 feet and then passes under cover. This outcrop is about 200 or 300 yards below the forks of this small Half Moon Creek.

It has been regarded from the days of the active furnace work as a most promising prospect of manganese and is always considered as one of the important resources of the area, but analysis shows it to be without trace of manganese. It apparently represents the clay with infiltrated iron and organic matter and is of no economic importance as shown by the following Survey analysis:

	Per Cent.
Metallic iron	19.98
Moisture	0.60
Loss on ignition	9.34
Silica	44.12
Iron oxide	28.40
Lime oxide	0.20
Manganese dioxide	None
Sulphur	0.02
Phosphorus	0.11
Titanium oxide	0.43

North of the Half Moon Creek with the so-called manganese outcrop and 230 feet higher is an outcrop of red to reddish-brown hematite on one of the terraces of Spring Knob. The bed follows a N. 40° E. course and has been opened across the inclined ore bed a distance of 30 feet by trenches and an old shaft. The ore is found in buff or yellow shale and is more or less laminated with bluish-black coating

on these parallel planes. The east wall is a heavy gray and brown sandstone with trend N. 40° E and dip of 36 degrees in direction N. 60 E, and the ore is opened close to this wall.

200 feet west of this wall is an opening in buff to grayish-brown shales with blocks of reddish brown ore associated with the clay. Fifty feet farther west the same ore is found in an opening in buff to brown shales. The shales in this opening dip 38° N. 50° to 60° W., and 30 to 40 feet farther west is a wall of sandstone similar to the east wall with a dip N. 50° W. The two ledges of sandstone represent the two slopes of an anticline with the crest removed by erosion exposing the anticlinal ore bed below in the Clinton shales. The 300-foot space between these sandstone walls is covered with large and small blocks of ore, and all the openings found the ore. The thickness of the ore cannot be observed in any of the shallow prospects.

Henry Bowers Shaft. To the southwest of the last exposure, and above the burnt house near forks of Half Moon run, a shaft was sunk to the ore by Henry Bowers. This shaft is said to be 60 feet deep and has been abandoned 50 years, but it was so strongly timbered that it stands today in good condition though half full of water. The ore as seen on the dump is compact and of light reddish-brown color with flakes of blue-black mineral through it, and the fracture shows a smooth glistening surface. Ore blocks of similar character are found along the mountain side following N. 40° E. direction. Its composition is shown by the Survey analysis given below.

At the southwest end of Spring Knob an old cut was made which exposes a cliff of Clinton ore 14 feet high 10 feet wide, and 60 to 70 feet long. Its direction is N. 50° E with a dip of 58 degrees S 40° or 50° E. The foot wall is a coarse brown sandstone and the ore seams run into it, forming near the wall a mixture of ore and sandstone. In the photograph (plate V-b) the sandstone wall is shown with ore near man's head. The ore is red in color with small black velvet patches, also bluish-black spots. Some of the ore is finely granular almost oolitic, looking like the typical

Clinton fossil red hematite of Grant county. It breaks with shaly fracture and glistening surface. It is compact and has the following chemical composition:

	Bowers Shaft.	End Spring Knob	Sterrett Survey.	Bank Ricketts and Banks.
Metallic iron	30.24	42.05	38.65	48.07
Moisture	0.55	0.56	0.24	.....
Loss on ignition	8.34	7.68	10.38	.....
Silica	32.75	22.69	21.26	11.66
Iron oxide	43.20	60.08	55.36	68.67
Lime oxide	0.08	0.32	0.22	.....
Manganese dioxide	0.09	None	2.19	0.40
Sulphur	0.01	0.045	0.01	0.014
Phosphorus	0.37	0.30	0.56	0.235
Titanium oxide	0.36	0.43	0.29	.....

Sterrett Mine. This mine was used in the earlier days of the Capon furnace as source of its ore. It is located on the Kline land northwest of Spring Knob and was worked by shafts, tunnels, and open cuts, which have long ago caved in. The old tunnels ran 800 feet into this ore along the bed, but its width cannot now be determined.

The ore is a deep brown color with black areas scattered through, giving a mottled appearance. It weathers to a yellowish brown and is slightly open or honeycomb in structure, and associated with buff shales and white clay. The level is 160 feet below the Half Moon mine, which lies in the direction of the trend of the strata S. 20° to 30° W. from the Sterrett mine. The composition of the ore on the dump is shown by the above Survey analysis.

Half Moon Mine. The Capon furnace in the later years of its history secured its ore supply mainly from the Half Moon Mountain, one of the spurs or ridges of North Mountain and 400 feet higher than the furnace.

The mine was reached by a tram road, and was worked by tunnels, open cuts, and two shafts. The elevation of the mine is about 500 feet higher than the Pee Dee, and the area covered by the old workings is 300 by 400 feet. The mine was worked first by a long entry and later by stripping in benches. The upper level is 30 feet wide and 200 feet long,

the next level 30 feet lower was worked 50 feet wide and 250 feet long with a shaft at the south end said to have been 40 feet deep through almost solid ore.

The ore is associated with buff shales, white and yellow clays, and in the open cuts was found in the form of nodules, some of which were three and four feet across. In the shaft which is completely closed, the ore is claimed to have formed a solid bed. The ore body dips 40° southeast, but it is practically impossible to determine its trend on account of poor exposures which are concealed by the caving of the banks.

This mine was visited by Mr. Guerard in 1875 when it was in operation and he gives the following description in the Centennial report by Maury and Fontaine (p. 268):

"The ore bank shows in an open drift of a 100 yards, a remarkable deposit of ore. Having sunk 70 feet on the vein which is inclined at an angle of 40°, it still appeared to be continuous. The deposit lies between sandstone and limestone, of which there is a large supply, and the outcrop can be traced some distance along the mountain. Three smaller veins of the same ore crop out above this larger one; and some hundred yards below, a vein of brown fossiliferous hematite, the counterpart of which has been worked at Bloomery, in Hampshire, has lately been discovered. It is 2 feet thick near the outcrop but has never yet been worked."

The following analysis made of the ore collected by Mr. Guerard in 1875 was made by Dwight and may be compared with the Survey analyses of ore taken in 1907 from surface and from lower level:

	Guerard Report.	Upper Level.	Lower Level.
Metallic iron	**45.00**	**49.17**	**42.22**
Moisture	6.695	0.04	0.24
Loss on ignition	0.295	10.11	9.13
Silica	11.771	17.70	22.16
Iron oxide	64.287	70.24	60.32
Lime oxide	2.657	0.12	0.66
Manganese dioxide	7.680	0.03	None
Sulphur	0.472	0.02	0.05
Phosphorus	0.483	0.20	0.20
Titanium oxide	.....	0.29	0.22

Plate V.—A.—Foot Wall of Ore Body at the Cold Short Mine, Capon Furnace Tract, Hardy County.

Plate V.—B.——Foot Wall of Ore Body at Spring Knob Mine, Capon Furnace Tract, Hardy County.

A sample of pig iron made from the Half Moon ore was analyzed in the Survey laboratory and contained:

	Per Cent
Metallic iron	93.58
Silica	1.05
Phosphorus	0.49

The ore in its upper portion is light brown in color with cavities filled with clay and ochre and has shaly fracture, but in the boulders from the lower level and from the shaft, it appears to be a deep brown solid ore with thin plates of bluish-black color possibly manganese.

End Half Moon Mountain. At the end of the Half Moon Mountain nearest the furnace above the old corduroy road, there is a good exposure of brown hematite ore, dark brown to almost black in color, with cavities containing minute pipes of ore. It is 90 feet above the road level, and above the ore to west is a wall of white sandstone, trending N. 60° E. and dipping 32°, N. 50° E. This ore was opened many years ago in trenches and pits along the dip of the bed which lies in a hard yellow shale and in line with the trend N. 60° E. Below is an outcrop of brown sandstone. The composition of this ore is shown by the following Survey analysis:

	End Half Moon Mountain.	Cold Short.	White Metal.
Metallic iron	54.58	38.08	24.31
Moisture	0.90	0.54	0.72
Loss on ignition	13.09	11.67	9.00
Silica	3.03	23.84	35.42
Iron oxide	77.97	54.40	36.16
Lime oxide	0.25	0.44	0.46
Manganese dioxide	0.017	0.06	1.17
Sulphur	0.01	0.12	0.01
Phosphorus	1.10	0.71	0.28
Titanium oxide	0.07	0.36	0.43

Cold Short Mine. The Cold Short Mine is located on one of the lower terraces of Spring Knob, one and a half miles west of Capon Furnace, and consists of several pits and trenches which have exposed a light brown ore, with a prismatic fractiure (see plate V-a). On weathering it tends

to crumble to small prisms. This ore was claimed by the furnace men to yield a brittle iron and so was designated as cold-short, and only used in small quantity in mixture with other ores. Its composition is shown in the above Survey analysis.

The Cold Short ore has also been opened by pits and trenches up the mountain over a vertical distance of 45 feet, and follows a direction N. 40° E. 180 feet higher in the Cold Short flat or terrace with three ore trenches following the same direction N. 40° E. and with ore similar to the lower openings, which would indicate a depth of ore of at least 180 feet at this place.

White Metal Mine. 25 feet above the Flat is an old opening locally known as the White Metal Mine, where a face of ore 22 to 24 feet high is exposed, nearly 40 feet wide, and 540 feet above the furnace. Its trend is different from the main Cold Short bed, running N. 50° to 80° E.

The ore has been followed in trenches and pits for several hundred yards east. The south wall of the ore is a hard white sandstone, dipping 46 degrees to southeast, while the main ridge near the Cold Short openings is composed of a smaller sandstone trending N. 40° E., thus forming a forked ridge at this place, and the ore bed apparently forks in same way or at least bends in direction. The White Metal ore was used for some time at the furnace in mixture with other ores. Its composition is given in the above Survey analysis.

Mellon Shaft. About one mile and a half west of the White Metal on a lower terrace, 400 feet below the level of the cold short flat is the Mellon shaft, 30 feet deep which was closed by caving of large boulder in 1854 so no measurements are possible at the present time.

The ore from this shaft was claimed by the old furnace men to be the best ore ever used at the furnace. An attempt was made to secure an average sample from the old dumps but with the length of time that has elapsed since the shaft was worked, this sample is of doubtful value in showing the real character of the ore. It has the following composition in the sample taken:

	Per Cent.
Metallic iron	47.26
Moisture	0.42
Loss on ignition	14.13
Silica	8.51
Iron oxide	67.52
Lime oxide	0.54
Manganese dioxide	3.75
Sulphur	0.002
Phosphorus	0.41
Titanium oxide	0.07

The ore was also opened in a trench with an exposure of calcareous shales trending N. 40° E. and dipping 28 degrees S. 30° E. The east wall is a brown sandstone trending N. 40° to 50° E. To the west is sandstone and limestone forming high cliffs in the ravine near Trout Run. The ore corresponds in position to the ores on the furnace tract below the brown sandstone in the Silurian rocks.

The iron ore on the dump has a bluish brown color with some pieces light brown and contains considerable dirt in the open cavities. The surface of a number of the blocks has a pitted or botryoidal surface, as though formed in bubbles, an appearance which by many people is taken as evidence of great heat or fire action involved in the formation of the ore, but it is due to water action.

Fossil Bank. Not far distant from this shaft and at nearly the same level in side of creek bank, is located the so-called Fossil Bank. At this place a reddish-brown ore is found in thin seams up to 4 inches thick interlaminated in light colored shales. A tunnel was driven back 10 to 12 feet on this ore but showed nothing of value. Clinton fossils were found in the ore stringers and shales.

Pond Mountain. A large vein of ore is found on Pond Mountain on one of the ridges of the North Mountain range, four miles southwest of the furnace, and 690 feet above the valley. Its outcrop was followed nearly 200 feet up the mountain, but its width could only be traced 8 feet, and then covered by rock debris.

The ore is dark brown to black in color, solid and of good weight. Its composition is shown by the following analysis by Mr. Glaser:

	Per Cent.
Metallic iron	45.28
Iron oxide	64.68
Silica	3.64
Sulphur	0.084
Phosphorus	0.173
Manganese	10.770

Rock Bank. This old mine is interesting in its well defined sandstone walls, giving the ore body a typical vein appearance. It is located on the side of Pond Mountain about two and a half miles south of Capon Furnace, 450 feet above the valley at the foot of the mountain and 580 feet above the furnace level.

The ore is enclosed by white compact sandstone walls which stand almost vertical and trend N. 40° E. The ore body is 2½ to 4 feet wide, and was worked in an open trench to a depth of 6 or 8 feet, and with a length of 200 feet. The ore is dark brown to nearly black in color, compact and hard. Some of it has a botryoidal surface, and in other places it is almost steel gray in color with few open spaces and these when present are free from dirt.

On the mountain 55 feet higher a cross trench was made which exposed a red hematite ore instead of the dark brown hematite in sand and shales. The dark brown hematite ore is found in loose blocks along the mountain side to the east of the Rock Bank, and is found next to the sandstone above the Jack Thorp coaling. The Rock Bank ore has the following composition:

	Rock Bank.		Flanagan Road.	
	Survey.	Ricketts and Banks.	Manganese Ore.	Brown Ore.
Metallic iron	58.66	53.43	10.38	39.20
Moisture	0.80	.....	0.78	0.30
Loss on ignition	10.17	.....	6.96	9.65
Silica	3.51	8.80	51.14	22.39
Iron oxide	83.80	.....	14.68	56.00
Lime oxide	0.47	.....	0.35	0.25
Manganese dioxide	Trace	0.10	6.25	2.53
Sulphur	0.016	0.12	0.0096	0.023
Phosphorus	0.91	0.813	0.31	0.49
Titanium oxide	0.01	.....	0.36	0.29

Flanagan Road Prospect. At the southwest end of the ridge of North Mountain above the Waites Run gap, one and a half miles south of Capon Furnace, an outcrop of brown ore is found which breaks shaly and is light in weight. The ore is 290 feet above the creek level and 500 feet above the furnace level.

Eighty feet higher a vein of brown hematite of better grade has been opened by a trench dug in a northeast direction. This ore was traced 72 feet higher and then concealed by a mass of large white sandstone boulders. The ore is found in buff shales and on the slope below is a heavy outcrop of the brown sandstone. The sandstone wall runs N. 40° E. and dips 50 degrees in a direction S. 50° E., the ore body coming between the upper white sandstone and the lower brown sandstone similar to the Pee Dee mine.

This ore body can be traced by boulders for a distance of 6 or 8 miles southwest. It is probably 500 feet lower than the red ore on top of the mountain. Sixty feet below the brown hematite ore is a mass of clay and shale ore streaks and nodules of a soft black mineral supposed to be manganese. It is a small water course below springs and the material appears to be a deposit from this water in the clay. Its composition and also that of the brown ore are shown in the above Survey analyses.

Bear Pen Prospect. Near the old bear pen on the Keller Capon Furnace lands at the end of the ridge of North Mountain above the last described prospect several trenches have been made in a red hematite ore which is close grained, shaly in character and breaks in long prisms with smooth glistening surfaces.

The ore is found in white and blue shaly clays. The foot wall is a brown sandstone trending N. 50° to 60° E. and dipping 44 degrees S. 40° E. and the ore comes in contact with the sandstone. Above the ore is a heavy ledge of very hard white sandstone which is exposed 27 feet higher than the highest ore opening. The trenches are opened 6 to 10 feet deep and are 8 to 10 feet long and while not connected are opened across the direction of the bed for a distance of

150 feet. This width which is probably greater than opened so far, is due to a folding of the bed in a syncline thus in reality representing the extent of the bed in width and not in depth. None of the holes is deep enough to show the thickness of the vein, being opened only a few inches in the ore.

These openings are almost due south of Capon Furnace about 2½ miles. They are 640 feet above the Pee Dee mine and 1,070 feet above the Capon furnace. No fossils were found at this place but the character of the ore, its association and level show it to be the same as at the Buck Thicket, or the Clinton ore. Its chemical composition and that of the Buck Thicket ore are shown by the following Survey analyses:

	Bear Pen.	Buck Thicket.	John Frye Land.
Metallic iron	42.00	24.47	45.25
Moisture	0.20	0.80	0.28
Loss on ignition	7.67	5.93	12.89
Silica	28.60	39.34	14.55
Iron oxide	60.00	35.96	64.64
Lime oxide	0.25	0.20	0.72
Manganese dioxide	0.41	0.13	0.72
Sulphur	0.02	0.01	0.006
Phosphorus	0.30	0.03	1.04
Titanium oxide	0.29	0.50	0.18

The John Frye land is on the lower slope of the mountain below the Bear Pen and Buck Thicket openings, and the ore is found in large blocks but not in place.

Buck Thicket Prospect. The Buck Thicket Prospect openings are located on the same North Mountain one and a half miles northeast of the Bear Pen prospect, on the Covert land. It is 1,200 feet above Waites Run. The ore is a red hematite shaly in structure, imbedded in yellow and red shaly clays. By barometer the level of the ore is 15 feet lower than the Bear Pen ore, and the white sandstone outcrops above the ore which dips into the mountain S. 40° E. at low angle. In the highest opening the ore bed was found 10 feet below the surface and at the lowest, it was 18 feet. A section of the last opening shows:

	Feet.	Inches
Clay shales	6	8
Red hematite	0	6
White clay	3	..
Red ore	0	10
Clay	2	..
Red ore	0	10
Brown sandstone with fossils	0	8
Brown clay	0	10
Red ore	2	6
Clay	..	..

The ore bed trends N 40° E, and the brown sandstone near the ore and some of the ore contain numerous fossils, Orthis, trilobites, etc., of Clinton types so that the ore and shales are Clinton. A similar outcrop is found one mile north in the Pitch Pine Log prospect trenches. This ore has therefore been followed for 2½ miles and probably extends to north and south of these prospects, continued to the southwest on the ridge to Waites Run gap also on the ridge to south of this gap.

Anderson Ridge Mine. On the land of William Barney on Anderson Ridge, one and a half miles north of Capon Furnace and to the west of Waites run is an old mine which furnished ore for the furnace. The ore was worked in a deep and wide open cut now caved in to large extent.

The ore varies from a deep brown hematite to masses of red hematite with glistening surface, and is more or less marked by black streaks and areas. Some of the ore is porous along parallel black planes. The cut was worked 35 feet in width and one shaft reached depth 30 feet. The west wall of the ore is a light brown sandstone trending N 50° E and nearly vertical and a wall of sandstone outcrops 75 feet east of the mine. The level of the ore is 400 feet above the valley. The composition of the ore is shown by the following Survey analysis:

	Anderson Ridge.	Lee Tract.
Metallic iron	34.16	43.96
Moisture	0.70	0.37
Loss on ignition	9.15	10.00
Silica	27.20	15.40
Iron oxide	48.80	62.80
Lime oxide	0.30	0.17
Manganese dioxide	0.04	0.79
Sulphur	0.01	0.04
Phosphorus	1.00	0.77
Titanium oxide	0.25	0.14

TROUT RUN AND THORNY BOTTOM AREAS.

Trout run empties into the Cacapon river at west edge of town of Wardensville, and at a number of places along this run the loose boulders of brown hematite show the presence of an ore body. These are seen on the Barney and Barney land not far from the county road two miles southwest but no openings have been made. Eight miles southwest by road is Perry post office where the Trout run valley forks, the west branch being known as Thorny Bottom, and on both streams to the south as well as to the north on Trout Run are a number of ore outcrops and a number of old prospects and mines.

Rudy Prospect. One mile north of Perry and to the east of the road on the Tucker Rudy land, are large numbers of ore blocks of brown hematite, with more or less honeycomb structure, found at the foot and on the lower slopes of the hill. This ridge is composed of heavy sandstone with trend N. 40° E. while below it is a mass of buff shales, or nearly black shales in unweathered samples.

An attempt was made to locate the ore bed in place, but the trenches were only excavated to a depth of 3 to 5 feet and not deep enough to reach below the wash and slip of the hill. The character of the loose blocks indicates the presence of a bed of good ore somewhere near this sandstone.

Crack Whip Furnace. One mile and a half up Trout Run south of Perry the stack of the Crack Whip furnace is still standing in good condition, though it has been abandoned 40 or 50 years (see plate IV-b). A number of mines were opened through the area within a radius of 5 to 6 miles

to supply ore though the main supply came from the Trout Pond region in Thorny Bottom.

Lee Tract. On the big Lee Survey of some 20,000 acres a number of openings have been made in the brown and red hematites, but only a few of these were visited. About one-half mile across the ridge to the northeast of the Crack Whip furnace is the so-called 22-foot vein of brown hematite which was used for a short time to furnish a portion of the ore for this furnace.

When this place was opened a few feet in depth, it showed a mass of large ore boulders of good weight and quality with a width of 22½ feet by actual measurement and followed a course N 30° E with a heavy sandstone wall 200 to 300 feet west of the opening. This wall is exposed 10 to 12 feet high, dipping to the east.

During the past year a force of men was set to work to open this deposit and it was found to be a mass of large boulders imbedded in buff shales and ten feet lower apparently gave way to shales. It is a boulder deposit and it is very doubtful whether any deeper work will show more of the ore. The real position of the ore bed is probably nearer the west sandstone wall, and from this have rolled the boulders now seen in this opening.

The high character of this ore and its compact structure with the absence of dirt give promise of a valuable deposit along this little stream valley. On the eastern side of the ridge, the ore was mined on a small scale according to statements of local people. The Lee boulder ore is 54 feet above the road and stream at foot of the ridge, and 230 feet above the level of the furnace. Its composition is shown by the above analysis.

Bulinger Knob. Up Thorny Bottom branch of Trout run three miles southwest of Perry is a narrow gap through the foot ridge of the main mountain divide (Devil Hole Mountain) between the two stream valleys. The ridge to north of this gap is known as Bulinger Knob, and to the south, as Bens Hill.

Bulinger Knob rises 235 feet above the valley, and on

its south point a brown hematite ore is exposed on the surface between two sandstones. To the west of the ore is a dark brown, coarse grained sandstone trending N. 40° E. and dipping 68 degrees N. 60° W. At the east of the ore is a light brown to white sandstone which dips 30°, S. 50° E.

The ore is found in white and yellow clay and is 10 feet wide and was followed to a depth of 27 feet where it was covered by surface debris. At the foot of the mountain the valley floor is a slaty blue limestone. The ore is light chocolate brown in color with parallel wavy lines more or less open. Black areas come in through the ore which is compact and rather hard. Its chemical composition and that of the Bens Hill ore are shown by the following Survey analyses:

	Bulinger Knob.	Bens Hill	Bens Hill Fossil Bank.
Metallic iron	42.89	38.96	42.00
Moisture	0.38	0.45	0.41
Loss on ignition	10.54	8.73	6.78
Silica	21.03	27.52	25.24
Iron oxide	61.26	55.68	60.00
Lime oxide	0.14	0.15	0.26
Manganese dioxide	None	0.04	0.017
Sulphur	0.03	0.012	0.09
Phosphorus	0.48	0.98	0.47
Titanium oxide	0.21	0.14	0.21

Bens Hill Prospect. To the south of Bulinger Knob across the little valley is Bens Hill which rises 280 to 300 feet above the valley to the ore horizon. The ore body trends N. 40° E. and dips 40 degrees S. 50° E. The foot wall is a brown sandstone with dip S. 60° E. The ore near the sandstone wall contains considerable sand, but farther away is a shaly reddish brown ore, with numerous fibrous layers of a variety of limonite ore known as Gothite. The surface ore is in form of flat plates of red hematite and below this layer breaks prismatic. It has been opened by three trenches which give an exposure of one-half mile long and 10 to 20 feet wide.

Bens Hill Fossil Bank. One mile S. 30° W. of the last

mine on this same ridge is an outcrop of red hematite locally known as the fossil bank though no fossils were found in the ore or associated rocks. The level of this outcrop is 420 feet above the limestone valley at the east foot of the ridge, and 665 feet above the valley at north end of ridge which would make this prospect 365 feet above the brown ore at north end of ridge.

The ore has been opened in a trench across the bed 8 feet and shows a bright red shaly hematite with black glistening areas, and breaks with smooth glistening surface. Some layers of brown hematite are found one of which was 10 inches wide at the top but it apparently grades into the red ore.

To the west of the ore body is a ledge of brown sandstone trending N 50° E, some red ore is found adhering to this wall. The whole ridge in this place shows small fragments of the red ore scattered over the surface. This sandstone is in places a conglomerate with small white pebbles. The east wall of the ore is a brown sandstone dipping N 50° W at an angle of 54°. The ore appears to be a Clinton hematite with the Medina sandstone foot wall. Its composition is shown by the above analysis.

Seger Prospects. The Seger prospect mines were opened on the west slope of Devil Hole Mountain almost due east of the Bulinger Knob and Bens Hill openings. The lower opening is 360 feet above the valley and is in form of trench, 8 to 10 feet wide, also two pits 25 feet apart east and west and worked out for a distance of 75 feet west. The ore was used for a time at the Crack Whip Furnace located northeast across the mountain, but was regarded as a cold-short ore.

The ore is in boulders in yellow and white clay following a direction N 70° W. The sandstone to the north runs N. 60° W. The ore is reddish-brown in color and breaks prismatic, and contains numerous glistening black areas. Its composition and that of the upper Seger opening are shown by the following Survey analyses:

	Upper Seger Mine.	Lower Seger Mine.	Five Mile.
Metallic iron	**41.05**	**44.13**	**34.72**
Moisture	0.50	0.35	0.22
Loss on ignition	11.02	9.65	7.73
Silica	15.18	14.60	34.74
Iron oxide	58.64	63.04	49.60
Lime oxide	0.20	0.12	0.58
Manganese dioxide	2.12	1.66	Trace
Sulphur	0.02	0.008	0.01
Phosphorus	1.22	0.54	0.14
Titanium oxide	0.29	0.21	0.21

The upper Seger opening is 270 feet above the lower, or 630 feet above the valley, and the ore is exposed in a trench and pit in blue and white clay. It is light brown in color somewhat shaly, but tends to break prismatic, with the surface fibrous gothite layers frequently present and also shining black areas.

The bed follows a direction N 60° E and can be traced for considerable distance along the mountain and possibly extends its entire length. The west wall of the ore body is a gray to bluish-gray sandstone which dips 34° to 36° in direction S 50° E. The ore comes in contact with this sandstone and stringers of ore are found in the wall rock. The ore apparently gives way at east to a sandy shaly rock, while the hill or ridge above is sandstone. The width of ore is about 20 feet.

Five Mile Bank. This old mine in the Trout Pond area is located about two and a half miles southwest of the Seger openings, and received its name on account of its supposed distance of five miles from the Crack Whip furnace, though the actual distance is about eight miles. Most of the ore used at this furnace is said to have come from this mine, and the ore was held in high favor.

The ore has a deep brown color with black areas through it and weathers on outside to a yellowish brown ochre, and breaks flaky or shaly. The west wall of the ore body is an irregular broken brown sandstone, shaly on exposed surfaces and contains ore mixed through it in cracks or fissures. It trends N 40° to 50° E and dips 60° in a direction S 50° E. The ore was worked in open cuts and in one shaft which is now full of water, and is associated with buff shales, and

white and yellow clay. It was worked 10 to 12 feet wide and appears to consist of a surface ore containing considerable dirt, with a better grade of shaly brown hematite below. The composition of the ore is shown by the above Survey analysis.

Gochenour Tract. On the F. Gochenour land, 2½ miles southwest of Wardensville or four miles by road, and on Chestnut Ridge, the ground is covered with blocks of solid, heavy brown hematite ore. The line of these blocks runs N 30° to 40° E, and associated with the ore are flint boulders and nodules containing numerous fossils, also blocks of blue limestone without fossils.

Attempts were made to locate the main ore body by trenches and pits, but only boulders were found in flaky buff shales and buff clay. The ore has a dark chocolate brown color with black velvet ore patches through it, and is free from dirt. The level is 990 feet by barometer above Wardensville. Followed to the south the shale and flint nodules are found on Grassy Knob, 135 feet higher. There is a valuable ore body on this tract but its exact position has not yet been located, and the trenches are not long or deep enough to intersect it. The composition of the Gochenour ore is shown in the following analyses:

	Survey	Glaser Analysis
Metallic iron	**40.10**	**45.28**
Moisture	0.43	.....
Loss on ignition	10.52	.....
Silica	20.58	18.19
Iron oxide	57.28	64.68
Lime oxide	0.16	.....
Manganese dioxide	0.50	0.270
Sulphur	0.012	0.043
Phosphorus	0.66	0.304
Titanium oxide	0.21	.....

The fossils in the flint nodules indicate the Lower Helderberg limestone horizon, the limestone having been mostly removed by solution, the insoluble flint nodules remaining, and the ore is probably at the Oriskany horizon.

Finley Prospect. On the Barney and Landacre 2,000 acre tract near the Finley house to the southwest of the

Gochenour land about one and a half miles, the brown hematite ore is found in large blocks scattered over a large area. A trench was dug in the field not far from the house, which showed the ore in large boulders probably not in place. It will require considerable more work to locate the exact position, and these boulders may only represent drift. The hole was shallow and is filled with water. The line of ore boulders follows a line approximately N 40° E. The composition of this ore is given below.

Baker Mountain. To the north and northeast of Wardensville is Baker mountain which rises to a height of 200 feet. There was at one time an old furnace located near its base, which used for a time the brown hematite ore from the slopes of the mountain and also used ore hauled from the Capon Furnace region. It was only operated a short time and was torn down 40 or 50 years ago.

John W. Frye Mine. On the land of John W. Frye near the foot of Baker Mountain, about one mile and a half north of Wardensville the ore was opened in the days of the old furnace. The ore has a honeycomb structure, with the pores filled with clay, and contains crystals of lime. It is found in buff shales with the limestone outcropping one-half mile west and trending N 30° E. Farther northwest in a ravine a black slate outcrops, forming the bank of the small run.

These loose blocks of ore with more or less lime streaks are found for nearly a mile along the foot of the mountain and are reported in larger quantity up the slope. The ore has the following composition:

	Finley Tract.		Baker Mountain Frye Tract.
	Survey.	Ricketts and Banks.	
Metallic iron	49.28	48.18	40.37
Moisture	0.13	.....	0.16
Loss on ignition	10.62	.....	10.97
Silica	15.64	16.40	22.44
Iron oxide	70.40	.....	57.68
Lime oxide	0.25	.....	0.91
Manganese dioxide	None	0.02	None
Sulphur	0.01	0.13	0.17
Phosphorus	0.48	0.43	0.32
Titanium oxide	0.07	.....	0.18

Plate VI.—Bloomery Furnace, Hampshire County.

CAPON SPRINGS AND LAFOLLETSVILLE AREA.

The brown hematite iron ore can be followed along the western slope of North Mountain by loose boulders of ore from the Capon Furnace tract northeast to beyond Lafolletsville in the southeastern portion of Hampshire county, and on beyond Rock Enon Springs in Virginia, or over a total length of 35 miles from Upper Cove of Lost River valley to Rock Enon Springs.

Capon Springs Area. Capon Springs one of the popular mountain resorts is located 14 miles northeast of Wardensville in Hampshire county. One mile up the mountain road to southeast of Capon Springs and on the left of the road, the ground is thickly strewn with boulders of brown hematite. The level is about 300 feet above the Springs, but no prospect work has been done and the exact location of the ore body was not found.

The ore has a honeycomb structure and is dark brown in color and appears around the openings as a solid heavy ore of good quality. From the size and number of boulders, there is possibility of finding a good body of the ore against the eastern sandstone ridge.

Farmer Lands. Six miles north of Capon Springs by road is the store known as Lafolletsville, and to the east and northeast on the ridges and slopes, ore blocks are thickly scattered over the ground. These are seen on the lands of Richard Lafollete, also on the B. S. Farmer and Davis Farmer tracts. These lands are close to the Virginia line and the ore extends across the line.

On the B. S. Farmer land the ore blocks follow a N 30° to 40° E line with sandstone wall to the east, and the ore is found over the ridge on the eastern slope on the McKeever land. The ore has a deep brown color, compact and of good weight. On the Davis Farmer land in an old orchard and in an abandoned field the ground is thickly covered with large and small ore blocks. This tract is northeast of the B. S. Farmer and Lafollete lands and the ore continues on a N 30° to 40° E line across the Good farm and on the Sheets and Moore-

head tracts. Farther northeast in Virginia at Rock Enon Springs, shafts were sunk many years ago striking good ore.

There is every indication of a very extensive ore body in this portion of Hampshire county, which deserves most careful prospecting, but no openings have been made in it, and very little attention has been directed to this area in the past. The ore is a light brown with a minute pitted appearance, and numerous patches of a black velvet ore. Its composition is shown by the following Survey analysis:

	Per Cent.
Metallic iron	46.85
Moisture	0.50
Loss on ignition	9.95
Silica	15.13
Iron oxide	66.93
Lime oxide	0.26
Manganese dioxide	0.28
Sulphur	0.025
Phosphorus	0.61
Titanium oxide	0.21

QUANTITY OF IRON ORE IN EASTERN HARDY AND HAMPSHIRE COUNTIES.

While more openings have been made in these iron ores of eastern Hardy county than any other area in the State, they are more or less scattered, and not wide or deep enough to enable one to estimate quantity with any degree of accuracy, yet probable estimates can be made which are of interest in showing the great possibilities of the area.

At one or two places the ore bodies have been followed down the mountain 180 to 200 feet, and they probably extend to the floor of the valley 350 to 400 feet if not farther. 200 feet may be considered conservative for depth of ore body until actual testing by the drill is made. Widths of 15 to 30 feet have been measured.

There is a bed of red hematite on the top of North Mountain traced 3 miles and it doubtless extends much farther.

The ore body near the white (Medina) sandstone has been followed along the North Mountain on more or less widely separated exposures for a distance of 35 miles, but it

also occurs on both slopes of the smaller ridges to the west which separate the valley of Waites Run, Trout Run, Thorny Bottom, which as followed would add 20 to 25 miles of outcrop.

There is the second body of brown hematite below the brown sandstone traced over 8 or 10 miles of outcrop, with possibility of being more extensive. There would be for all the ore bodies a total length of outcrop not far from 70 miles. There is at present time not enough data to determine the average width of the ore over this outcrop, nor is it possible to state that the ore is continuous over this entire distance. It is in all probability cut out here and there and probably widens and narrows along the outcrop. There is another ore body at the contact of the Helderberg limestone and Oriskany sandstone only observed at a few places but it may prove to be an extended deposit. There are the Lost River ores probably near the Lower Silurian limestone, whose extent is not known.

The possible additions to the ore supply will probably compensate the error of over estimating the ores on North Mountain and adjoining ridges. If we assume this length of ore bodies to be 50 miles with average width of 15 feet and depth of 200 feet, there would be 30,000,000 cubic yards of ore, or 75,000,000 tons which would run five 500 ton furnaces a hundred years. Thorough prospect work and drilling will in all probability increase this estimate rather than lower it, and probably 100,000,000 tons would be nearer a correct estimate.

TRANSPORTATION.

There is not a mile of railroad in Hardy county or eastern Hampshire county. A number of surveys have been made in past years for railroads, connecting with the Baltimore and Ohio or the Southern lines in Virginia. There are three possible routes from Wardensville, two of which have been surveyed a number of years ago.

One of these possible routes is to the southeast connect-

ing with the Southern railroad near Edinburg, passing from Wardensville up Waites Run and through the low gap between Mill Creek and Paddy Mountain, and down Stony Creek to Edinburg. This line would be about 28 miles long. The elevation at Wardensville is 1,200 feet, and 2,150 feet at the highest point in the Paddy Mountain gap, or a rise of 950 feet in a distance of 12 miles or about 80 feet to the mile, or 1½ per cent grade. The elevation at Edinburg is about 900 feet or a fall of 1,250 feet in a distance of 16 miles or nearly 80 feet to the mile. A narrow guage road from Edinburg to Liberty Furnace now extends up Stony Creek along this proposed route.

A second possible route is from Wardensville to Winchester following the Cacapon valley to one mile south of Yellow Springs, there passing up the small creek valley past Lafolletsville, and through a gap to the north and past Rock Enon Springs, thence southeast through one of the gaps in the Little North Mountain to Winchester. This line would be 36 to 40 miles long and the grade would rise from 1,200 feet at Wardensville to 1,300 feet at the gap near the Frederick, Virginia county line, and 800 feet at Winchester.

The third possible outlet would be to the north following the Cacapon river valley to the Potomac where the road would connect with Baltimore and Ohio and Western Maryland. This line would be 80 to 90 miles long with low grades, and could be built with little difficulty to north of Capon Bridge. Here the river flows through a narrow gorge reported to be too narrow for a road, but this gorge was followed in the course of the present study, and there is room for a road except for a distance of a few hundred yards possibly at its south end where the roadbed would have to be blasted in the side of the rock cliff.

It is reported that north of the Forks of Cacapon, a gorge closes in with the river flowing between vertical rock cliffs, but the river might be left to the east at the Forks and the road follow some one of the smaller valleys. This portion of the road will require a careful engineering survey to determine a practical route.

A railroad built into these counties, in addition to opening a large iron ore area would also reach an important timber belt of pine, oak, chestnut, chestnut oak with its bark, hickory, etc., covering many square miles. It would also give an impetus to farming and grazing in the fertile valleys of the Cacapon and its tributaries. After the timber is cut from many of these mountain ridges, there will be available a good limestone soil of remarkable fertility. Experiments have proven that these mountain slopes are especially well adapted to orchards and vineyards.

With a standard guage road at Wardensville, it would be possible to connect the various valleys with the main line by either narrow or standard guage branches, reaching the still smaller valleys with tram roads. It would be possible at minimum expense of construction to assemble these ores from the various districts above described at Wardensville. Whether this point would be the proper place for the erection of blast furnaces or not, would be a question for discussion. The ore and limestone would be available at this place and the coke would have to be brought in so that it would probably be better to ship the ore to the main line railroads there to meet the coke or to be transported to existing furnaces at more or less distant points. If the railroad was constructed along the north route, the ore could be shipped to the Potomac, and the coke brought to that place. There are advantages in both locations, and a careful study of cost of materials, freight rates, labor conditions, etc., would have to be made before the question could be practically answered.

CHAPTER IX.

THE IRON ORES in MONROE and GREENBRIER COUNTIES.

GEOGRAPHY OF MONROE AND GREENBRIER COUNTIES.

Monroe county, located in the extreme southeastern corner of the State, was formed in 1799 from part of Greenbrier, and was named in honor of James Monroe, President of the United States. Its area is 464 square miles[1] with a population of 13,130, and county seat located at Union near the center of the county. The mean annual rainfall is 50 to 60 inches, and mean annual temperature 50° to 55°.

The county is bounded on the north by Greenbrier county; on the east by Craig and Allegheny counties, Virginia; and on the west by Summers county. The only railroads in the county are the Chesapeake and Ohio crossing the northwestern corner at Alderson for a distance of about three miles. A branch line of the Norfolk and Western through the Potts Creek valley in the southeastern portion of the county is graded and will probably be completed during the present year. Alderson on the Chesapeake and Ohio railroad is 11 miles northwest of Union, or 20 miles by road. It is 269 miles from Washington and 118 miles east of Charleston.

Union, the county seat, is a town of 350 people with hotel and stores, and from this place, the drive can be made to the iron districts 16 to 20 miles southeast. Union is located 7½ miles from north line of the county, 8 miles from south line, 12½ miles from east line, and 10 miles from

[1] Statistics in these sections from U. S. Geol. Survey, Bull. 233, Gazeteer of West Virginia.

west county line. It may be reached by a drive of 20 miles from Alderson, or 19 miles from Ronceverte, and a daily stage runs from Fort Spring, 17 miles north of Union, all of these towns being on the C. & O. railroad and represent the nearest railroad points to Union. In this county are a number of summer resort hotels located at well-known mineral springs as, Salt Sulphur Springs, Red Sulphur Springs, Sweet Sulphur Springs, Rocksalia Springs.

Greenbrier county is located north of Monroe, and was formed in 1777 from portions of Montgomery and Botetourt counties, and named from the river. Its area is 1,051 square miles with a population of 20,683, and county seat at Lewisburg in the southern part of the county.

The mean annual rainfall is 50 to 60 inches, and mean annual temperature 50° to 55°.

The county is bounded on the north by Nicholas, Webster, and Pocahontas; on the west by Fayette and Summers; on the south by Monroe; and on the east by Alleghany county, Virginia. The Chesapeake and Ohio main line crosses the southern portion of the county from east to west, a distance of 25 miles. A branch of this road from Whitcomb just east of Ronceverte extends northward across the county 25 miles, thence across Pocahontas county to Durbin where it connects with the Coal and Iron division of the Western Maryland. From White Sulphur north to the Anthony creek valley a standard guage lumber railroad 22 miles long has been constructed but is only used for log trains. A railroad 6 miles long connects Ronceverte with Lewisburg.

Lewisburg, the county seat, is a town of 1,016 people, good hotel and general stores, livery, and is the location of a prosperous ladies' seminary. It is located 20 miles from the north county line, 8 miles from the south line, 17 miles from the west line and 12 miles from east line. Ronceverte, six miles south of Lewisburg on the C. & O. railroad is a lumber shipping point: and White Sulphur Springs ten miles east on the same railroad, is one of the popular summer resorts. The iron ore country can be reached by driving from White Sulphur or by longer trip from Lewisburg.

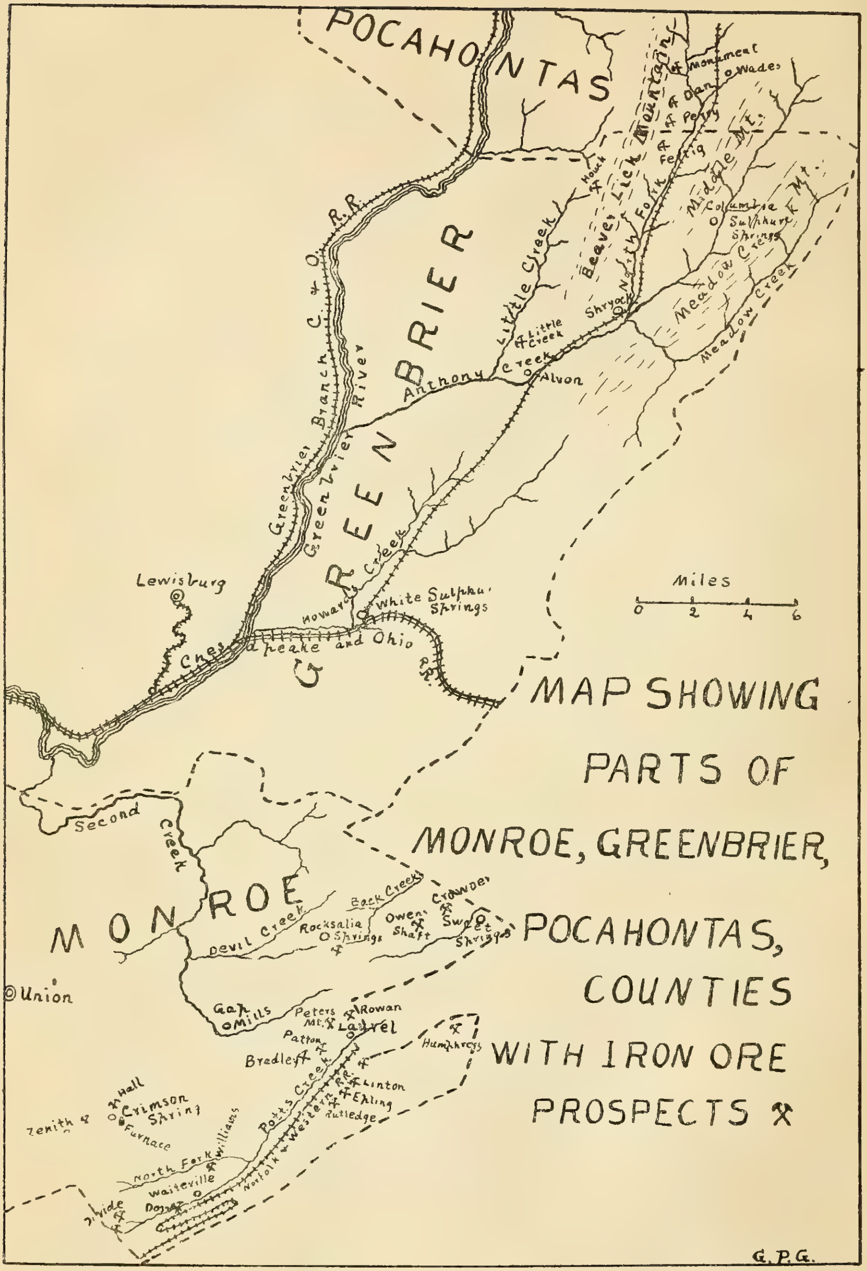

Fig. 11. Map showing Iron Ore Prospects in Monroe, Greenbrier and Pocahontas Counties.

TOPOGRAPHY OF MONROE AND GREENBRIER COUNTIES.

The eastern and southern portions of Monroe county are traversed by mountain ridges trending N 50° to 60° S, with deep valleys between. The central and north central portions include a broad valley, while the western portion of the county is a fairly level plateau with higher knobs or hills, and cut by a number of small creeks.

To the west of Union the plateau region has an elevation of 1,700 to 2,200 feet with knobs rising to 2,500 and 2,810 feet. Wolf Creek Mountain at the northwestern corner of the county forms a ridge four miles long with a northwest trend and elevation of 2,500 to 2,700 with one high knob 2,810 feet, and this area is drained by Wolf Creek and its small tributary runs. The western portion of the county is drained by Indian Creek and its branches with a valley 1,700 to 1,800 feet high while the average height of the plateau is 2,000 feet. A short distance west of Union is a ridge made up of a number of high knobs known as Swopes Knobs which reach 3,000 and 3,300 feet. This ridge trends northeast for five miles, and extends three or four miles further south with an elevation of 2,300 to 2,500 feet. The southwestern portion of the county has an elevation of 2,000 to 2,200 feet and is drained by Brushy run. The streams at north and northwest flow into the Greenbrier river, and at southwest into the New River.

The central and northern valley region with Union located at its western edge has an elevation of 2,200 feet at the north, 2,400 feet at the south and is surrounded by ridges. It is about five miles wide and 12 miles long. Its waters reach the Greenbrier by the northward flowing Second Creek, so it is sometimes called the Second Creek valley. This creek rises near the Alleghany Divide where an elevation of 50 feet or less separates the eastward flowing waters to the James from the westward to the Ohio. This point is six miles east of Gap Mills, and the creek flows west in this mountain valley passing through two narrow gaps in the

Gap and Middle Mountains, thence flowing northwest in a winding channel to the Greenbrier river east of Fort Spring in Greenbrier county. The creek is 28 miles long. Its elevation at the source is 2,600 feet, and at its mouth 1,700 feet, or a fall of 32 feet to the mile.

In the eastern and southern portions of the county the parallel mountain ridges with the valley between form a characteristic feature of the topography. The most northern ridge is known as Cove Mountain, six miles long with an elevation of 3,000 feet and one peak reaching 3,425 feet. It is separated by Devil Creek valley from Middle Mountain. This narrow valley has an elevation of 2,400 to 2,600 feet and the creek is a tributary of Second Creek. Middle Mountain has an elevation of 2,700 to 2,800 feet, and North Mountain with an elevation of 2,700 to 2,800 feet, north of the gap reaches 3,000 feet. It is 12 miles long to the Virginia line and continues northeast in that state. To the southeast of Middle Mountain is the Back Creek valley which slopes from a middle divide to the east and west and has an elevation near the divide of 2,600 feet reaching 2,000 feet at east line of the county.

Gap Mountain to the south of this valley has an elevation of about 3,000 feet and is 12 miles long, separated by the Sweet Spring valley, with an elevation of about 2,500 feet, from Peters Mountain which extends from New River and forms the south county boundary over nearly half the distance, and again forms a portion of the south-eastern county boundary. Its length is 36 miles, and it continues through Virginia under the name of Sweet Springs Mountain. It rises from the Sweet Spring valley to a height of 3,500 feet or a rise of 1,000 feet in less than a mile. To the south of this range is the Potts Mountain forming a southern border of Monroe county at the southeast, and separated from the Peters Mountain by the Potts Creek valley. Potts Mountain reaches an elevation of 3,500 to 3,800 feet and a length of over 30 miles to the northeast corner of Craig county, Virginia. The Potts Creek valley is 12 miles long in Monroe county and one-half to one mile wide. Its elevation at

southwestern corner of the county is 2,800 feet and 1,900 feet at eastern line. The slope to Peters Mountain is steep, while toward Potts Mountain, it is broken by a number of short ridges 3,000 to 3,200 feet high.

Greenbrier county is crossed from north to south by the Greenbrier river, with a marked contrast in topography to the east and west of the river especially in the central and southern portions of the county. To the west of the river is a wide plateau extending nearly to the western line with an elevation of 2,200 to 2,400 feet. Over this area rise short ridges, giving a very uneven surface with elevations ranging from 2,400 to 4,000 feet.

To the east of the Greenbrier river, there is a parallel series of long northeast-southwest ridges separated by narrow and deep valleys, and across these ridges pass two well marked transverse valleys, Howards creek at the south which cuts across the Greenbrier Mountain west of White Sulphur, and Anthony's creek eight miles north. The prominent mountain ridges at the south are Greenbrier Mountain 3,000 feet, and its southward continuation White Rock Mountain. Further east is the parallel ridge broken into Kates Mountain, Bobs Ridge, and Coles Mountain 2,500 to 3,000 feet high; and forming the eastern line of the county is the Alleghany Mountain about 3,000 feet elevation.

Anthony's creek at the north forms a broad valley between the Meadow Creek Mountain on the east and Beaver Lick Mountain on the west. Its elevation is 2,000 to 2,400 feet, and is a half to one mile wide. The lumber railroad of the St. Lawrence Lumber Company follows this valley to the North Fork where it turns north along this stream. The Meadow Creek range has an elevation of 2,500 to 3,000 feet and is deeply indented by gorges and ravines, and is crossed by the Meadow Creek gap. Beaver Lick Mountain is cut by stream valleys in a similar way giving very irregular slopes and reaches an elevation of 2,500 to 2,800 feet. It is in this range that the iron ores have been prospected, showing a large quantity of ore.

GEOLOGY AND STRUCTURE.

The surface rock of the western half of Monroe and Greenbrier counties is the Greenbrier Limestone of the Lower Carboniferous, a bluish gray limestone of variable chemical composition, but reaching in portion of the area a high degree of purity. To the east the valleys are cut in the Devonian shales, while the mountain folds expose strata from the Lower Silurian limestone to the Devonian, and to the Clinton of the Upper Silurian in Greenbrier county. The rocks of these different formations are similar in character to those in the counties further north, already described.

The structure involves an alternation of synclines and anticlines more or less broken and eroded. In the iron ore belt of Potts Creek valley of Monroe county, the creek valley is a synclinal fold with the Devonian black shales exposed over its surface. As the slope of the mountains is followed toward the top, lower and lower formations are exposed, reaching the Medina and Clinton on the crests. On both sides of the valley are the anticlinal ridges, Potts and Peters Mountains. The structure of this area is illustrated in figure 12. The structure in the ore belt of Beaver Lick Mountain in Greenbrier county is similar to that of the Potts Creek area.

Bibliography. The W. B. Rogers geological survey reports of 1835-1841 give a number of notes and geological sections in Monroe county, in the western portion of Greenbrier county, and near White Sulphur Springs. Brief notes on the iron ores of the two counties are given by Maury and Fontaine in the Centennial report of West Virginia for 1876.

The Potts Creek valley of Monroe county and more especially its continuation eastward in Virginia have been investigated by a number of expert engineers and geologists, and further down the valley are a number of operating mines and furnaces. Reports on these ores for the mining companies have been made by Prof. D. W. Langdon Jr., in November 1889 and 1891; by Dr. Edward Orton in March 1890 and February 1891; by Captain Joseph E. Johnson in Febru-

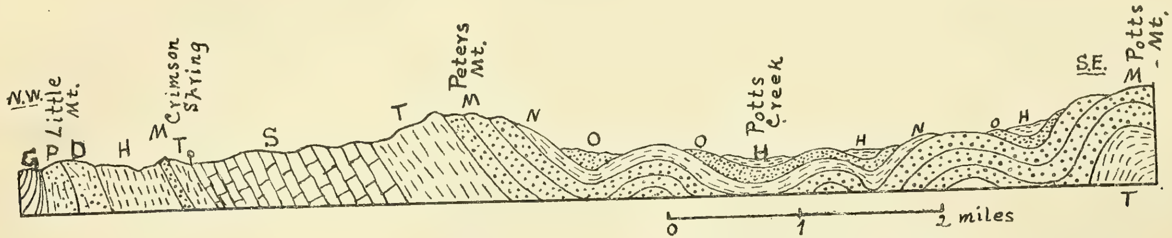

Fig. 12. Geological Section across Potts Creek Valley, Monroe County (after Rogers).

G. Greenbrier limestone.
P. Pocono sandstone.
H. Hamilton shale.
D. **Catskill.**
O. Oriskany.
N. Niagara.
M. Medina.
T. Trenton shales.
S. Shenandoah limestone.

ary 1897; by A. E. Lehman in February 1891; by Henry Gilmer of Lewisburg in 1890 and 1891; by Dr. F. W. Ihne in August 1894. The last two reports refer to the ores mainly in Monroe county and were published in pamphlet form. Extracts from the other reports were given in a pamphlet compiled and issued by Judges H. A. Holt and A. C. Snyder in October 1891. All of the reports are now out of print and difficult to find. Through the kindness of Mr. R. B. Holt of Lewisburg, son of Judge H. A. Holt, the three pamphlets mentioned above have been secured, and many facts from them are incorporated in the present chapter.

In Greenbrier county in the Beaver Lick Mountain, a very complete examination and study was made in 1907 of the iron ores by Mr. John Fulton, Mining Geologist of Johnstown, Pa. The work of prospecting and opening these large ore bodies is now being vigorously prosecuted under the supervision of Mr. Fulton who has kindly furnished the writer a copy of his report and map. This information served as a valuable guide in the present field study of this area, and portions of Mr. Fulton's report are included in the discussion of this area.

Mines and Prospect Openings in Monroe County.

Crimson Spring Mine. Crimson Spring is located 9 or 10 miles southeast of Union, one mile north of Peters Mountain. North of Squire Hall's house across the county road is the old mine which supplied ore to the old Crimson Spring furnace, the ruins of which are standing to the south of the road, and abandoned 50 or 60 years.

At this mine the ore is found in a mixture of flint and lime fragments, with shales below. It was worked in an open trench toward the north for about 20 feet on the side of the hill, and the ore can be traced a short distance up the ridge. The west wall is an irregular mixture of flint and iron standing as a solid face, four feet wide, while the east wall consists of white and blue flint dipping 80° west. The ore body is apparently 10 to 12 feet wide, and the west wall

Plate VII.—The Crowder Tract Prospect Opening in Brown Hematite, Monroe County.

further back is an irregular limestone breaking nodular, with strike N. 30° E. The ore is a brown hematite probably in or near the Lower Silurian limestone, and represents a replacement of the limestone, with the flint remaining. It is a light brown hematite or dark brown in some blocks, and shows considerable sand. Its composition is shown by the following Survey analysis:

	Crimson Spring.	Zenith.
Metallic iron	47.44	54.09
Moisture	0.09	0.80
Loss on ignition	10.03	8.78
Silica	20.02	9.22
Iron oxide	67.82	77.29
Lime oxide	0.20	0.30
Manganese dioxide	Trace	0.035
Sulphur	0.02	0.03
Phosphorus	0.56	0.16
Titanium oxide	0.07	0.11

Zenith Area. Zenith is located 2½ miles southeast of Crimson Spring. On the ridge, about half way between the two places, are numerous nodules or boulders of an irregular brown hematite associated with flint fragments. The strata dip steeply southeast and trend N 60° E. About one mile northeast of Zenith, a bed of brown iron ore was found 8 to 10 feet wide with a wall of white flint on the west and a pink flinty rock to the east. The bed trends N 30° to 40° E. and apparently has the same relation to the other rocks as found in the furnace mine. The ore is a light brown hematite of good quality, according to the analysis.

Over this ridge are numerous boulders of ore but no openings have been made, and similar boulders are reported from the slope of Little Mountain to the north of Zenith. There are indications of a considerable quantity of this ore probably in beds of good width, through the Crimson Spring and Zenith region, and its quality so far as developed at the present time is encouraging. However, it must be remembered that very little work has been done in opening the veins, and until such prospect work is made, it would be im-

possible to express any accurate opinion on quantity or quality of the ores.

Potts Creek Valley. The Oriskany iron ore district of southwestern Virginia is reported as including an area of 2,100 square miles, 70 miles long, and 30 miles wide, while the Potts Creek valley portion is 37 miles long of which 12 miles are in Monroe county, West Virginia.

At the mouth of Potts creek near Covington, Virginia, and in the Jackson and James river valleys, are located the Covington, Longdale, Lowmoor, Princess, and other furnaces, and the various Oriskany mines supplying the furnaces with brown hematite ores. The area is about 100 miles distant from the New River, Flat Top, and Gauley River coke fields with excellent transportation facilities over the Chesapeake and Ohio and Norfolk and Western railroads.

The West Virginia-Virginia state line crosses the Potts Creek valley 24 miles southwest of Covington. This portion of the valley to the east and west has been held back in its development by lack of railroad. The branch of the Norfolk and Western will soon be completed extending from the west across Potts mountain and down the valley through length of Monroe county into Virginia. The greater part of the route is now graded and a large force of men is at work (1907). With the completion of this road, the ore district will be accessible and should then readily attract capital for iron ore development.

The ore deposits of the lower portion of the Potts Creek Valley have been carefully prospected during the past 20 to 25 years and a number of expert reports made by trained engineers who seem to have been greatly impressed with the quantity and quality of the iron ores. The upper portion in West Virginia being remote from railroads received less attention. In order to understand the possibilities of the West Virginia area, a number of quotations from the reports on the lower portion of the valley will be given.

Dr. Edward Orton who was state geologist of Ohio to the time of his death, and ranked as one of the leading geologists of this country, made two reports on the Virginia por-

tion of the Potts Creek valley, and reported as follows on the quantity and continuity of the Oriskany ores in this area:[2]

"In none of the numerous outcrops does the ore show a thickness of less than twenty feet. In a part of the territory it exceeds thirty feet in thickness. This subdivision of the ore field, and especially the Upper Bennett bank, furnishes by far the finest showing of limonite ores that I have ever seen. * * * *

"I have asserted the continuity of the ore only where it is demonstrable, but the several outcrops on the Peters Mountain side of the valley give full warrant in my judgment, for inferring its existence throughout all this territory. If it were strictly continuous, as a geological horizon, the facts of its outcrop would be just what they are now. But in this subdivision of the valley there is enough ore in sight to justify large expenditure in the way of development. The ore is in all cases well situated for profitable mining, and the country carries all of the timber that would be required in the largest exploitation of the field.

"In summarizing my conclusions as to the quantity of the ore, I may say that there are two districts of the region which I have traversed and reported upon, that will certainly admit of large ore production from as many centers as are desirable. These are the Paint Bank field including the Humphrey's land,[3] and the Bennett and Helper tracts last described. There is also a favorable outlook for a large production from the Given neighborhood, including the Loup Bank. Further, I see no reason to doubt that large tracts of ore as valuable as any that are now exposed, remain to be uncovered by the miner.

"All the present exposures of the seam are geological accidents, depending upon the structure and topography of the particular district in which they occur, and the fact that they are found where they ought to be found if the seam were continued, gives us, as I have before remarked, the best

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[2] Quoted in pamphlet, The Iron Ore Beds in Potts Valley, Virginia, by H. A. Holt and A. C. Snyder, p. 16; 1891.

[3] The Paint Bank field is near the West Virginia line and the Humphrey's opening is in Monroe county.

warrant we could have for inferring this continuity of deposit. When followed underground and away from the outcrops, I should expect the seam to behave as it does in the present workings of the great furnace mines to the northward. It would shrink and expand within the limits of the formation. Pockets of fifty feet in thickness are sometimes found, but there is compensation to be made for such bonanzas in all cases by shrinking at other points. The great mines already in operation seem well satisfied when they can carry a working thickness of 15 to 20 feet. The Potts Creek Valley will certainly not fall below this measure."

Dr. Orton gives the following analyses of these ores as made by N. W. Lord:

									Average.
Iron	49.90	50.03	51.94	50.00	49.90	49.90	55.50	56.00	51.70
Silica	11.61	13.26	10.15	9.67	15.76	12.05	4.45	10.69	10.95
Manganese	0.18	0.11	0.14	2.96	0.39	0.25	0.29	0.09	0.55
Phosphorus	1.64	2.78	0.65	0.68	0.18	0.95	1.07	0.18	0.70

He concludes from these analyses: "The Potts creek ores will certainly give a larger yield of iron than any of the Oriskany ores now worked in Virginia. They can be depended upon for nearly fifty per cent of iron."

Concerning the ore represented by the last analysis above with 56 per cent iron (Upper Bennett bank), Dr. Orton speaks of it as, "the finest outcrop of brown hematite in Virginia, is at the same time the richest and purest ore of its class."

Concerning the relation of structure to ore outcrops, in the Potts Creek valley, Dr. Orton states: "It is an Oriskany valley of most favorable structure. In the long slopes of the two great ranges that bound it, and in the several minor and parallel folds that traverse the valley proper, provision is found for a vast expansion of the formation which can be reached to full advantage."

Captain Joseph E. Johnson manager of the Longdale furnace and mines in his report on this Potts Creek property gives some interesting facts bearing on duration of ore supply

and depth of these Oriskany ores, from his long experience in the working mines in Alleghany county, Virginia. These facts are of especial interest and importance because in West Virginia, no mines have ever been worked to any depth and no drillings made so that the possible depth of the ore bodies has been an unknown quantity.

Captain Johnson writes as follows in his report Feb. 1891: "To give a better idea of the extent of these measures as compared with others, I may mention that at Longdale, mining has been carried on, under its present owners, for nearly twenty years, and nearly all of the ore used has been obtained from less than two miles of the measures; at Lowmoor the length upon the measures is not more than two miles; at Dolly Ann and Iron Mountain not over five miles; at Stack Mines less than one mile; at Princess less than one mile; and at Victoria not over one and a half miles.

"'The best outcrop at Longdale has been followed down vertically 500 feet, and for years has been extensively worked from a tunnel in the ore 380 feet below. Another tunnel is now being driven 120 feet lower to the foot of a trial shaft, at the bottom of which the ore continued on down with a thickness of twelve feet. At the Princess they have had a similar experience, their lowest level being, I am informed, 500 feet below the outcrop."

Mr. A. E. Lehman, mining engineer from Pennsylvania, in his report on these ores calls especial attention to the facilities for economical working of the ores and states that, "in numerous cases they are so persistent as to suggest possibilities of a continuous trench out of which ore might be dug. * * * Much of the ore can be gained by simple open cut work. In fact, this mode of attack will be applicable to most if not all the localities named. A very large quantity of excellent ore is obtainable before a continuance of operations will involve complex methods of mining."

PROSPECT OPENINGS AND OUTCROPS.

Attention will now be given to the outcrop and prospect openings of the iron ores in Monroe county, West Virginia. When the above reports were made over the line in Virginia, the Monroe county lands were owned by a different company and very few openings had been made. Very soon afterward, attention was directed to the ores of the upper portion of the valley and a number of prospects opened. Since that time a number of these have caved and the shafts filled with debris and water, not permitting examination at the present time. Trouble was also experienced in finding guides or persons who knew the exact location of these openings in the mountains. In order to make the report more complete accounts of these old openings are included from the reports especially of Mr. Gilmer and Dr. Ihne who visited the locality at the time the prospects were opened. There is every indication and reason to believe that the favorable reports of the numerous openings in the Virginia portion of this valley will apply to the upper portion. There is certainly a large quantity of valuable ore in this area, but to prove the extent and quantity will require numerous openings along the lines of outcrop, and with the presence of a railroad through the center of the valley, the time has come for this work. It is one of the objects of this chapter to attract the attention of iron ore companies to the great possibilities of this section of the state.

Rowan Prospect. This opening is in Virginia but less than a mile from the state line. It was visited by Dr. Ihne in 1894, who gives the following notes on this prospect. The opening is located on the slope of Peters Mountain, 300 feet above the valley. The Oriskany ore was uncovered over an area of over 100 square feet and to a depth of 2 feet where it appears as a solid mass of dense dark brown limonite visible above and below the opening and while incompletely opened gives indication of a very large deposit. The ore according to Dr. Ihne has the following composition:

	Per Cent.
Metallic iron	59.10
Silica and insoluble	2.50
Metallic manganese	0.15
Phosphorus	0.40
Sulphur	Trace

Little Mountain Clinton Ores. The ridge between Potts Mountain and the valley from opposite Laurel to the west with a length of 24 miles in Monroe county is known as Little Mountain and is divided by cross creek valleys into minor ridges which have received local names as Linton, Motisearge and Rutledge Ridges and Kyers Mountain. They reach a height of 3,000 to 3,400 feet or 800 to 1,100 feet above the valley.

The Clinton ore has been opened in a number of prospects along the line of these ridges, but these were shallow and are now nearly closed. In the prospects on Rutledge ridge one mile back of Harvey Epling's house, or one and a half miles from the Potts Creek road and 700 feet higher, the ore is associated with a white flinty rock and red clay. The foot wall is a reddish sandstone with stringers of ore near its surface. This rock dips 60 degrees N 40° W, and trends N. 45° E. The ore is a hard compact almost flinty ore with surface weathering to a yellowish brown. Its composition according to the survey analysis is as follows:

	Per Cent.
Metallic iron	52.29
Moisture	0.11
Loss on ignition	9.67
Silica	11.67
Iron oxide	74.37
Lime oxide	0.21
Manganese dioxide	Trace
Sulphur	0.01
Phosphorus	0.81
Titanium oxide	0.07

This ore is said to have a thickness of 2 to 5 feet, but it was not possible to make any measurements on account of the debris in these openings. The opening was in the form of a trench worked to the south, and to the north down the slope a number of pits or wells were opened some of which reached the ore body.

This Clinton flinty ore was reported from a number of places along Little or as it is sometimes called Middle Mountain, and the early reports on the area state it is continuous through this mountain. Mr. Gilmer in his report states that five openings between Linton's Run and Trout Run on Linton's Ridge, one opening on Motisearge Ridge and two on Rutledge Ridge, show 8 feet of ore on this mountain. He further says: "This ore is as regular as a leaf in a book throughout this distance of six miles, and can be seen nearly the whole distance varying in thickness from 3 to 10 feet, standing almost perpendicular, and exposed at an elevation of nearly 900 feet above the bed of the creek but cut in three places in this distance by streams flowing out of the back valley into Potts creek. The ore will average 5 feet in thickness all this distance."

Mr. Gilmer gives the following analyses of these ores as made by Mr. Henry Froehling:

	Motisearge.	Linton Ridge.		
Metallic iron	50.22	45.92	52.09	51.80
Silica	15.34	21.20	12.74	13.02
Metallic manganese	0.14	0.10	0.11	0.10
Phosphorus	1.04	0.66	1.25	1.06

Dr. Ihne in his report gives the following analyses of these ores:

	Linton Ridge.	Rutledge.
Metallic iron	46.50	44.25
Metallic manganese	0.10	0.10
Silica and insoluble	16.30	25.50
Phosphorus	1.00	0.75

Peters Mountain. While but few prospect openings have been made on this mountain, ore is found in loose blocks nearly its entire length in the Potts Creek area. To the north of Laurel P. O., about one and a half miles, on the mountain road 460 to 500 feet above Potts creek, a bed of red hematite cuts across following a direction N 20° to 30° E. It is exposed over a width of 10 to 14 feet, and its thickness is apparently 2 to 3 feet.

To the east of the ore is a wall of hard white sandstone

and above the ore to the top of the mountain is a series of red shales and red sandstone. The ore breaks in slabs and blocks and is bright red in color and represents the Clinton red hematite. In a second outcrop there is a heavy exposure of brown hematite mixed with a small quantity of red hematite. The ore has not been opened but the outcrop can be followed for some distance. The composition of the two ores is shown in the following Survey analyses:

	Peters Mountain. Hematite.	Peters Mountain. Limonite.	Mark Patton. Tract.
Metallic iron	**48.10**	**41.74**	**53.20**
Moisture	0.20	0.10	0.08
Loss on ignition	5.10	9.77	10.52
Silica	23.74	11.82	5.84
Iron oxide	68.91	59.61	74.02
Lime oxide	0.21	0.36	1.20
Manganese dioxide	0.039	0.49	0.49
Sulphur	0.01	0.01	0.02
Phosphorus	0.55	0.10	1.01
Titanium oxide	0.25	0.18	0.14

Mark Patton Land. The hill to the northeast of W. Mark Patton's house two and a half miles west of Laurel is thickly strewn with large blocks of brown hematite of good weight and quality. This ore was followed up the hill to the Oriskany sandstone outcrop, where the blocks of ore are especially abundant.

The ore has never been opened but from the number and character of the loose ore boulders, this is a promising tract for prospect work. The ore is dark brown in color with numerous black glistening areas. Some of the blocks show small globular or botryoidal surfaces composed of fibrous gothite iron. Its composition is shown by the above analysis.

Jeter Land. Further west and two miles east of Waitville, Mr. Jeter has opened in the valley two trenches running northeast-southwest in a soft sand which shows streaks of ore, but nothing of value. On Peters Mountain to the north of the Jeter house, an opening was made in ore a number of years ago. One of these openings, the Arthur, shows 5 feet of Oriskany ore according to Mr. Gilmer.

A little over a mile west of the Arthur is the Bradley prospect in the Oriskany brown hematite. This opening was visited by Mr. Gilmer when it was made. He describes it as a hard, brown ore of good quality, five feet thick and opened for 100 feet, with the following composition:

	Per Cent.
Metallic iron........................	58.83
Silica	2.82
Metallic manganese..................	0.21
Phosphorus	0.44

Williams Prospect. On the North Fork of Potts Creek one mile north of Waiteville on Fork Mountain on the land of Henry Williams, the Oriskany ore is found in loose blocks, but its thickness could not be determined. It was never opened to any extent, but from its position belongs at the Oriskany horizon. Its composition according to an analysis by Mr. Henry Froehling for Mr. Gilmer is as follows:

	Per Cent.
Metallic iron........................	48.50
Silica	17.67
Metallic manganese..................	0.27
Phosphorus	1.02

Doss Prospect. In the upper Potts Creek valley on South Fork about four miles east of the western line of Monroe county is the store and post office known as Waiteville, and about three miles to the southwest of this place are the ore openings on the Doss farm. The eastern opening shows a small body of ore apparently between flint on the west and the irregular brown Oriskany sandstone on the east. This sandstone trends N 60° E. and dips to the northwest. The ore at the present time is not well exposed in this opening.

The opening to the northwest shows the sandstone wall dipping to the northeast, and is 15 to 18 feet thick with 10 feet of ore on the hill above it. The ore has been opened in a trench 40 feet long and 15 feet wide. It is 100 feet above the road or at an elevation of 2,900 feet. The ore is light brown in color with the surface layers more or less open or honeycomb in texture. It contains small black velvet areas,

also minute botryoidal surfaces. Its composition according to the analyses made by Henry Froehling for the Gilmer report and by Dr. Ihne are as follows:

	Froehling. Per Cent	Ihne.	Ihne. Selected Sample.
Metallic iron..........	51.95	53.25	59.20
Silica	14.85	7.50	2.50
Metallic manganese....	Trace	0.10	0.15
Phosphorus	0.59	0.65	0.60

The following analysis was made in the Survey laboratory from an average lot of ore:

	Per Cent.
Metallic iron	51.38
Moisture	0.23
Loss on ignition....................	11.85
Silica	10.43
Iron oxide...........................	73.54
Lime oxide...........................	0.30
Manganese dioxide..................	0.02
Sulphur	0.02
Phosphorus	1.06
Titanium oxide.....................	0.07

At the western line of Monroe county on South fork of Potts Creek at an elevation of about 3,000 feet, two openings are described by Dr. Ihne, as follows, in his report of 1894:

"Several years ago an exploration hole of about 6 to 7 feet was made, but which nearly half has been filled up again. This opening is located close to the wagon road at the Low Gap and at the water-shed between the head waters of the Potts and Big Stony Creek, and also close to the boundary of West Virginia and Virginia. At the left corner of this hole, stands on the wall an edged piece of fair, compact, brown iron ore 18 inches thick. * *

"About 700 feet in a northwestern direction from the last described point, upward on the easy slope of the Peters Mountain, the high crest of which is distant 1,000 to 2,000 feet, is another large opening in form of a trench of about 12 feet in length and 6 feet in width. * * * Besides the many boulders to be found, it seems also that a solid ore bank of from 4 to 6 feet thickness is in place there, but re-

garding the strike and dip of the vein, an accurate determination cannot be made any more." Dr. Ihne gives the following analysis of the ore at the first opening:

	Per Cent.
Metallic iron	53.30
Silica	5.75
Metallic manganese	0.10
Phosphorus	0.50

North of Peters Mountain is the Sweet Spring valley separated from Back Creek valley by Gap Mountain. Sweet Spring is one of the well known summer resorts and has long been patronized by people from the south and north. In the Gap Mountain region iron ores are supposed to exist in large quantity and a few prospect openings have been made in recent years.

Crowder Prospect. The H. C. Crowder farm is located on the southern slope of Gap Mountain, over a mile back from the valley road and two miles southwest of Sweet Spring, in the eastern part of Monroe county. Boulders of brown hematite ore are very common on this land, and a large opening was made 100 feet long and 10 to 12 feet wide on the side of a hill or knob, shown in the photograph, plate VII.

The length of the trench was supposed to represent the thickness of the ore body, but an examination of the trench shows the ore lies between two sandstone ledges which dip about 30 degrees east. The ore trends N 60° E and has a thickness of 6 to 8 feet. It was followed over the low hill for a distance of 200 feet across the bed, with a shallow cover of shales and sand and was opened by small pits. The same ore body was found across the small creek valley to the northeast where it has been exposed in two or three prospect holes. It is associated on this side of the creek or run, with sandstone and flint nodules. A number of the hill slopes in this area show numerous loose boulders of ore and indicate a possibility of a considerable quantity of good brown hematite ore.

The ore on the Crowder land is light brown in color with shaly fracture along black glistening planes. Its composition is shown by the following Survey analysis:

	Per Cent.
Metallic iron	49.56
Moisture	0.17
Loss on ignition	11.47
Silica	18.52
Iron oxide	64.40
Lime oxide	0.26
Manganese dioxide	0.065
Sulphur	0.02
Phosphorus	1.26
Titanium oxide	0.18

Owen Shaft. On the John Owen land at the top of Gap Mountain, three miles west of the last prospect, and a mile north of the valley road, a large amount of prospect work has been carried on. A trench 290 feet long, 6 feet deep, was made in the red soil and flint gravel, showing small scattered pieces of iron ore. This main trench runs nearly east and west, and from it trenches were driven to the northwest 90 to 100 feet, which showed practically the same material as in the long trench.

A square timbered shaft was made 50 or 60 feet deep to the east of the trenches, and is now half full of water, and no data could be obtained. From the dump at side of shaft, it is evident that near the bottom a lime and flint brecciated rock was found associated with nodular and botryoidal masses of a steel black ore probably manganese. The ore also forms a cement around flint fragments in some blocks. The nodules are ½ to 3 inches in diameter, hard but brittle, and composed of pipes of short columns rounded in outline. The level of the top of the shaft is 340 feet above the water in Back Creek, and no ore in quantity was found except in the shaft. The composition of this steel gray ore is given in the following Survey analysis:

	Owens Shaft.	Rocksalia Springs.
Metallic iron	3.64	54.22
Moisture	0.28	0.49
Loss on ignition	11.26	12.24
Silica	13.29	3.43
Iron oxide	5.19	77.42
Lime oxide	1.00	0.30
Manganese dioxide	24.80	0.017
Sulphur	0.02	0.02
Phosphorus	0.22	1.23
Titanium oxide	0.11	0.04

Rocksalia Spring. One mile back of the hotel at the Rocksalia springs located near the divide of the waters of Back creek and Little Devil creek, on the north slope of Gap Mountain, 340 feet above the level of the spring, an opening was made some years ago in a body of brown hematite. The ore body trends N 20° to 30° E., and is opened over a width of 8 to 10 feet, with a thickness of 3½ feet near the outcrop.

A section of this opening shows,

	Feet.
Yellowish white sandstone	3
Brown hematite ore	3½
Red sandstone	1
Blue and gray flint	8

The ore is somewhat sandy near the wall, and has a dark brown color with a decided vitreous luster, and is compact in texture with good weight. Its composition is shown in above analysis.

On top of Little or Gap Mountain 560 feet above the level of the spring is a heavy outcrop of red brown sandstone with fossils, associated with a coarse flint breccia rock and red hematite which is 4 to 6 feet thick. A section of the rocks near the summit shows,

	Feet.
Hard white sandstone	......
Flint breccia	6 to 8
Red hematite and flint	4 to 8
Red or brown sandstone	......

The ore blocks are quite abundant over the slope on both sides of the top of the mountain, and they break shaly and are sandy in texture. The horizon is apparently the Clinton.

GREENBRIER AND POCAHONTAS COUNTIES.

To the northeast of White Sulphur Springs is a long mountain trending northeast, which is divided by cross valleys into shorter ridges all of which are claimed to contain valuable Oriskany ore deposits. The first of these ridges is known as Bobs Ridge and was prospected some years ago with a few openings near its crest which are reported as showing a promising body of ore. Next to the north is Coles Mountain with ore boulders but no openings. To the north of the Anthony creek gap is the Beaver Lick Mountain, on which ore openings were made 8 or 10 years ago, and a considerable amount of prospect work done especially near the north line of the county in the North Fork country. During the past year (1907) and at the present time, active prospect work is in progress under the direction of Mr. John Fulton, the well known mining geologist of Pennsylvania. Mr. Fulton has kindly given the writer much valuable information about this area, both before and since the study of the region for the present report. The ore openings on the Beaver Lick Mountain will now be described.

Fertig Prospect. The Fertig prospect is located on the Anthony's creek slope of the Beaver Lick Mountain, 20 miles northeast of White Sulphur, or ten miles north of Anthony creek gap. It is located on the side of a small ravine cutting into the mountain, 1¼ miles to the west of the lumber railroad and 570 feet higher than this road.

This prospect is an open cut about 30 or 40 feet wide, 75 feet long, and 20 feet deep. It shows a mass of rounded boulders above resting on large rounded masses of ore apparently in place, and associated with flint and limestone fragments. The foot wall is yellowish brown irregular sandstone, the Oriskany which trends N 30° E and dips 30 degrees in a direction S 50° E. The hanging wall is not clearly marked, but is apparently a weathered limestone which near the ore body is in form of small fragments associated with flint. A trench driven 20 feet across this material showed

little change, but along the mountain side the limestone boulders are numerous.

The ore body has been opened to a depth of 20 feet and in width varies from 25 to 35 feet. The angular flint fragments are found in some of the blocks surrounded by ore. This ore is porous or honeycomb with the open spaces filled with fine soft sand and almost black in color. The following analyses of this ore are given by Mr. Fulton, the first made for a report by Mr. Lehman, and the second for Mr. Fulton's report. The third analysis was made in the Survey laboratory from a sample taken in the course of the present study:

	Lehman Report.	Fulton Report.	Survey.
Metallic iron	61.53	60.20	58.23
Moisture	.....	.....	0.27
Loss on ignition	.....	7.67	7.53
Silica	1.55	2.80	4.56
Iron oxide	.....	.....	83.19
Lime oxide	.....	.....	0.24
Manganese dioxide	....	0.17	0.035
Sulphur	.....	.....	0.07
Phosphorus	0.492	0.342	0.61
Titanium oxide	.....	.....	0.36

Perry Prospect. One and a half miles northeast of the Fertig just over the county line in Pocahontas county, is the Perry opening, 450 feet above the railroad track and a mile and a quarter distant. The ore has been opened in a large cut 70 feet wide and 15 to 25 feet deep, showing 50 feet of ore. The foot wall is the brownish Oriskany sandstone which dips 36 to 40 degrees in direction N 50° E., while on the hill above the ore are limestone and flint fragments (see plate VIII).

The ore is very porous and almost steel gray in color, but weathers to a red soft ore on the surface. It is free from sand and clay and appears to be of good quality. The boulders of ore are found especially abundant at a point 180 feet lower in a ravine indicating the possibility of a very large ore body in this hill.

The composition of the ore according to the Lehman, Fulton, and Survey analyses is given below:

Plate VIII.—Perry Mine on Beaver Lick Mountain, Pocahontas County.

	Lehman Report.	Fulton Report.	Survey.
Metallic iron	**53.31**	**53.20**	**59.23**
Moisture	.....	.....	0.23
Loss on ignition	.....	7.22	5.02
Silica	7.60	13.50	7.24
Iron oxide	.....	.....	84.67
Lime oxide	.....	.....	0.24
Manganese dioxide	.....	0.18	0.02
Sulphur	.....	.....	0.22
Phosphorus	.....	.....	0.19
Titanium oxide	.....	.....	0.07

Dan Prospect. The Dan opening is located 1¾ miles northeast of the Perry and one and a half miles west of the railroad and 325 feet higher. A large open cut or trench gives a section of the ore body. In some former prospect work, four tunnels were driven in this trench to intersect the ore body. The top tunnel is 15 feet above the second which is 20 feet above the third, and the fourth is 45 feet lower.

The two upper tunnels were about the level of the ore body but were driven in the wrong direction. The two lower tunnels were made below the ore body in the foot wall. The bottom tunnel was 380 feet long and runs in a N 30° W. direction and no ore appears in its walls. A considerable quantity of ore was blasted from the ore body in the open cut, but the tunnel work was apparently a failure (see plate IX).

The foot wall of the ore body is a yellowish sandstone weathering to sand, and the ore is mixed with it in a nodular form in its upper portion. This sandstone which is the Oriskany, trends N 30° E., with a dip of 30 degrees in direction S 50° E. The ore body shows in this opening with a thickness of 40 feet. It is dark brown in color, compact in texture except for scattered small pores. Its composition is shown by the following analyses:

	Lehman report.	Fulton report.	Survey.
Metallic iron	**49.25**	**50.60**	**58.93**
Moisture	.....	.....	0.19
Loss on ignition	.....	.....	11.26
Silica	8.90	13.41	2.01
Iron oxide	.....	.....	84.22
Lime oxide	.....	.....	0.20
Manganese dioxide	.....	0.11	0.02
Sulphur	.....	.....	0.02
Phosphorus	0.336	0.402	0.72
Titanium oxide	.....	.....	0.07

Monument Prospect. The Monument openings were made three-fourths mile northwest of Dan and one mile west of the railroad at Mr. Wade's house, and 390 feet above the railroad. A large open cut was made into the ore at this place on the side of one of the foot ridges of the main mountain. The ore was found in a large body in place and 20 feet in thickness. The foot wall is a brown sandstone trending N 30° E., with a dip of 40 degrees in a direction S 50° E (see plate III-b).

The ore is a dark brown hematite, compact in texture with an uneven fracture and contains black streaks irregularly distributed through it. The ore has been exposed in pits up this ridge to a height of 45 feet above the open cut. Sixty feet lower and 10 feet above the bottom of the small ravine, a tunnel was driven 100 feet in a direction N 60° E., to intersect the ore body but at this distance did not strike the ore except in form of a few scattered boulders.

The following analyses of the ores in the open cut of the Monument prospect were made for the Lehman and Fulton reports, and by the Survey of an average lot of the ore:

	Lehman report.	Fulton report.	Survey.
Metallic iron	**45.34**	**37.10**	**36.77**
Moisture	.....	.....	0.10
Loss on ignition	.....	9.43	5.92
Silica	21.50	34.81	37.26
Iron oxide	.....	.....	52.54
Lime oxide	.....	.....	0.22
Manganese dioxide	.....	0.07	0.02
Sulphur	.....	.....	0.02
Phosphorus	.....	.....	0.92
Titanium oxide	.....	.....	0.07

Hauck Prospect. The Hauck prospect was not examined, but Mr. Fulton states that it is located on the west slope of the mountain on the side of a deep valley and at present out of reach by the railroad. The ore is lower grade than most of the openings above described on the eastern slope of the mountain. Mr. Fulton gives the following analysis of this ore:

	Per cent.
Metallic iron	39.50
Silica	27.36
Manganese	2.06
Phosphorus	0.266
Volatile matter	9.80

Little Creek Prospect. The Little Creek openings are located near the southern end of Beaver Lick Mountain, one and three-fourths miles northeast of the Anthony Creek gap, and on the western slope of the mountain. This location is about 12 miles northeast of White Sulphur, and has long been regarded as a most valuable prospect, with the ore body reported as 40 to 60 feet thick. The level of the lowest opening is 550 feet above the Anthony Creek valley to the east.

Seven openings have been made, some of which show a promising body of ore, but they have not been made deep enough or extensive enough to form any safe conclusions as to the value of this ore body, and it would justify further work. The course of the ore is N 20° to 30° E., and the dip at the lower opening is S 50° E.

In the first and lowest opening in the form of a long trench 6 to 7 feet deep small ore nodules are found in clay and sand which are streaked with iron, but no quantity of ore was observed. As the ore is followed to the northeast in the different trenches, nothing of value is found in the second; but in the third trench, there is a good body of ore in nodular form 18 to 20 feet wide, and opened to a depth of 8 feet. The level of this opening is 10 feet above the first.

45 feet higher is the fourth trench with similar boulders of ore. The fifth opening is 27 feet higher and shows the N 30° E trend with a dip to the southeast. The boulders

have been opened to a depth of 4 feet and show good ore. The sixth opening farther northeast is at the same level as the fifth and shows only small pieces of shelly ore, with angular pieces of white sandstone cemented by black iron. In the seventh opening, 27 feet higher no ore was seen, but numerous small blocks of brown and white sandstone. The top of the mountain 40 or 50 feet above, is composed of white sandstone.

The ore as found in these trenches is a dark brown hematite with scattered openings lined with dark brown velvet ore, and has good weight. The following analyses are given of this ore in the Lehman and the Fulton reports. The Survey analysis was made from an average lot of the ore from the third opening:

	Lehman report.	Fulton report.	Survey.
Metallic iron	54.61	53.00	53.59
Moisture	.....	11.50	0.30
Loss on ignition	.....	.....	10.50
Silica	8.50	7.84	9.40
Iron oxide	.....	.....	76.57
Lime oxide	.....	.....	0.22
Manganese dioxide	.....	0.32	0.02
Sulphur	.....	.....	0.02
Phosphorus	0.42	0.676	0.61
Titanium oxide	......	.....	0.07

Quantity of Ore. The length of the outcrop as explored of this brown hematite ore on the eastern slope of the Beaver Lick Mountain is 12 miles. The thickness of the ore at the different openings is 30 to 50 feet. If allowance be made for loss of ore in the ravines and the thickness be assumed as 30 feet and worked to a depth of 100 feet, there would be along this slope 12x5280x30x100=7,000,000 cubic yards of ore. With a weight of 2½ tons to the cubic yard, there would be 17,500,000 tons of ore. If the ore continues in the same way on the other side of the mountain as indicated in the few openings made, there would be a total of 35,000,000 tons of brown hematite ore. The depth of this ore will probably reach at least 200 feet which would double the above estimate.

The ore will doubtless continue several miles north. With the railroad in the valley below and the ease of construction of a branch road up Little Creek to reach the ores on the western slope of the mountain, and with the possibility of large deposits of Oriskany ore on the ridges to the south as shown in the openings on Bobs Ridge, this district is certainly one of great promise. The active work now in progress in the thorough study of these ores by a prospective mining company will doubtless lead to an early development of the Beaver Lick Mountain ores.

On the top of the mountain near the county line and north, the Clinton fossil red hematite ore is found, and the samples of ore brought from this locality show a very heavy ore of apparently high grade, but little is known of the thickness of the ore as no prospect work has been done on this ore outcrop.

IRON ORES IN JEFFERSON AND BERKELEY COUNTIES.

Jefferson County. The only operating iron mine in the state of West Virginia at the present time is located on the Potomac river in Jefferson county, four miles above Harpers Ferry at a point named Orebank and it is reached by a switch from the Baltimore and Ohio railroad from Engles station by way of the Bakerton limestone quarries. This mine was opened nearly 100 years ago, and is now owned and operated by Joseph E. Thropp of Everett, Pennsylvania, who ships the ore to the furnace at Earlston across the river from Everett, where it is mixed with lake ores.

The ore is mixed with red clay and forms the surface cover 1 to 20 feet in thickness over the Shenandoah limestone over many acres in this region. The open fissures in this limestone 2 to 25 feet wide and now opened to a depth of 140 feet in one place, contain this material with ledges of boulder brown hematite reaching a maximum of 2 feet in thickness. The surface clay and ore are mixed with sandstone and flint water worn boulders, which are only partially

separated in working the ore, many of them being loaded in the car with the ore.

The ore is washed in two washers which give a capacity of 40 to 50 tons daily, and much of the clay is thus removed. 50 to 60 men are employed and a small engine is used to haul the ore from the pits to the washing plant. Most of the ore shipped is the washed clay ore, but the ore boulders are taken as they are found in the fissures forming a very small part of the ore mined. The following analyses were made of the boulder ore and the washed clay ore:

	Jefferson county lump ore.	Jefferson county washed ore.	Berkeley county.
Metallic iron	41.21	44.14	38.63
Moisture	0.27	0.40	.....
Loss on ignition	10.03	9.88	.....
Silica	20.75	19.70	35.98
Iron oxide	58.87	63.04	55.17
Lime oxide	0.26	0.30	.....
Manganese dioxide	1.40	0.39	.....
Sulphur	0.02	0.03	.....
Phosphorus	0.31	0.28	.....
Titanium oxide	0.21	0.05	.....

Berkeley County. Just south of Martinsburg on the Faulkner farm, near the limestone quarries of the Standard Lime and Stone Co., a number of years ago prospect pits were sunk to open a brown hematite or limonite ore which attracted considerable attention at that time and some of the ore was shipped away.

The ore is a limonite, more or less sandy, and found in honeycomb nodules full of dirt, also in the form of pipes. It is irregularly distributed and apparently not in any solid body. As the pits are followed to the west to the magnesian limestone belt the ore seems to disappear. Similar deposits of iron ore are reported north of town, and the ore at all these localities is 600 to 800 feet to the west of the high grade limestone. Its composition on the Faulkner farm is shown by the above analysis:

CHAPTER X.

THE IRON ORE INDUSTRY AND ITS RELATION TO WEST VIRGINIA.

There exists a common and wide-spread opinion that the state of West Virginia does not contain iron ores in any quantity or value, and in the estimation of iron ore reserves, this state is often omitted or dismissed with very few words. Reference to the past history of the iron industry of the state which centered around the various charcoal furnaces confirms this impression. Most of these stacks were located so as to work ore beds 8 to 18 inches thick containing 25 to 30 per cent metallic iron and often remote from lines of transportation. They were operated with profit at a time when pig iron commanded a very high price. With present prices, the cost of the iron would be greater than the selling price, and the probability is they will not be considered of value until a far distant day when all the iron ore deposits of the country are exhausted.

If these carbonate iron ores of the Coal Measures only are taken into account, West Virginia could not attract any attention as a possible source of iron ore, and a report on them would be of little or no value. The state, however, possesses other deposits of iron ore which are worthy of most careful investigation. These deposits of red and brown hematites along the eastern mountain border, are unknown to most of the citizens of this state and are not considered in estimates of the state's mineral wealth. They have been overlooked by iron ore investors, and it is one of the objects of the present report to call attention to this possible source of added wealth.

A study of the preceding pages will show that the quality of ore present in these mountain counties would justify

mining operations. The quantity is the important question for solution. The analyses show an iron content of 40 to 52 per cent with an average of 42 to 45 per cent. Lake Superior iron ores which to-day furnish the greater portion of iron used in this country show a higher average, but this average has been declining steadily and the time is not far distant when this percentage will not be much above that of the West Virginia ores. According to Eckel the iron percentage in the Lake Superior ores has been declining about 1 per cent a year.

The amount and nature of the impurities in the ore must also be considered, as these factors will lower the value of an ore which may otherwise contain a high percentage of metallic iron. The West Virginia iron ores in percentage of impurities are of lower grade than Lake Superior ore, but are similar to the southern ores of Virginia, Alabama, etc. They are usually high in silica which makes them more difficult to reduce, involving a higher fuel consumption and greater labor cost; but with decrease in supply of purer ores, ores higher in silica are in demand.

The West Virginia ores are too high in phosphorus for use in manufacture of Bessemer steel. They are non-Bessemer ores and could only be used for open-hearth steel.

During the past years of the great American steel development, Bessemer steel was the most important branch of the industry and practically all the steel manufactured was Bessemer, while open-hearth steel attracted much less attention. As long as this condition prevailed, high phosphorus ores had a very limited market; but this condition is rapidly changing and open-hearth steel will in short time surpass Bessemer in quantity.

The first open-hearth steel furnace in the United States was built at the Cooper-Hewitt Iron Works at Trenton, New Jersey, in 1868 (Swank). The first Bessemer steel rails were made according to Stoughton, in 1867, and the first open-hearth rails in 1878.

The following statistics from Mr. James M. Swank's reports of the American Iron and Steel Association are of

interest and very instructive in showing the growth of the open-hearth steel industry:

	Bessemer steel, tons.	Open-hearth steel tons.
1867	2,679	
1868	7,589	
1869	10,714	893
1870	37,500	1,339
1875	335,283	8,080
1880	1,074,262	100,851
1885	1,519,430	133,376
1890	3,688,871	513,232
1895	4,909,128	1,137,182
1900	6,684,770	3,398,135
1901	8,713,302	4,656,309
1902	9,138,363	5,687,729
1903	8,592,829	5,829,911
1904	7,859,140	5,908,166
1905	10,941,375	8,971,376
1906	12,275,830	10,980,413
1907	11,667,549	11,549,088

According to the 1907 statistics of Mr. Swank, open-hearth steel was made in 136 plants in 20 states, as compared with 125 plants in 20 states in 1906, and 111 in 17 states in 1905.

Mr. Benjamin Talbot, the English iron and steel expert, states in a recent article,[1] that the Bessemer process has passed the zenith of its growth and in England has been outranked in production by open-hearth steel. He gives the following three reasons for the rapid increase in production of open-hearth steel:

1. The ever growing scarcity of iron ores suitable either for acid or basic Bessemer steel.

2. The superiority of the product obtained by the open-hearth process of manufacture.

3. The cheapening of the production of the steel ingot by modern open-hearth methods of manufacture.

He further states that high carbon and low phosphorus rails in the basic open-hearth process give rails of greater reliability and better wearing qualities. Such rails contain about 0.75 per cent carbon and 0.04 per cent phosphorus.

1. Open Hearth Steel Rails, in Iron Age, Feb. 28, 1907; p. 656.

The advantages of open-hearth steel over Bessemer are given by Stoughton as follows:[2]

(a). The open-hearth process being slower, more attention and care can be given each detail. This is especially true at ending of the process, for if Bessemer process is continued a second or two too long, the bath will be highly charged with oxygen to its detriment, and under normal conditions there will be more oxygen in the metal at end of the Bessemer process than in the open-hearth.

(b). Bessemer steel contains more nitrogen and hydrogen thought to be detrimental. The excess is due to the moisture in the blast.

(c). The heat of the Bessemer process depends upon the impurities in the pig iron and especially on the amount of silica. The heat is also regulated according to the judgment of the operator and his skill in estimating the temperature of the flame. Irregularities therefore result at times and produce effect on the steel, as the temperature at which the ingots are cast should not be too high or too low, while in open-hearth process the temperature is also regulated by judgment of the operator, more time is afforded for judgment and for the control of the heat.

(d). In the Bessemer process, the carbon is first removed and then the metal is recarburized to the desired point. In the open-hearth process, the operation can be stopped with any desired amount of carbon, and then recarburized to a small amount, so that greater homogeneity is secured in high carbon steel.

Campbell (p. 14) in his treatise on iron and steel, states that, "Most American metallurgists and engineers agree that open-hearth steel of a given composition is more reliable, more uniform, and less liable to break in service than Bessemer steel of the same composition."

Campbell further states (p. 24) that the Association of American Steel Manufacturers in 1895 agreed that Bessemer steel will do for buildings, highway bridges, and similar

2. Metallurgy of Iron and Steel, p. 60; 1908.

ANALYSES OF WEST VIRGINIA IRON ORES.

PENDLETON COUNTY

Survey No	MINE OR PROSPECT	Metallic Iron	Iron Oxide	Silica	Manganese Dioxide	Phosphorus	Sulphur	Lime Oxide	Moisture	Loss on Ignition	Titanium Oxide	Kind of Ore
47	Ann Smith	52.14	74.48	13.36	0.03	0.32	0.001	1.22	0.50	3.26	0.11	Hematite
61	A. J. Pitzenbarger	55.21	78.88	9.14	0.04	0.76	0.02	0.94	0.50	3.85	0.14	"
62	A. J. Pitzenbarger	52.03	74.35	9.64	0.02	0.71	0.06	1.76	0.35	6.36	0.18	"
51	T. F. Bowman	57.09	81.59	6.07	0.04	0.59	0.01	1.30	0.52	2.75	0.11	"
56	Bible Knob	50.07	71.36	11.74	0.04	0.67	0.03	2.46	0.90	4.39	0.07	"
53	Moatstown	41.22	58.90	26.76	0.02	0.17	0.07	0.30	0.45	3.92	0.21	Limonite
55	Dave Eye	42.44	60.65	25.40	0.02	0.33	0.11	0.34	0.53	4.28	0.29	"
52	Elkins Tract.	34.42	49.19	32.30	0.065	0.32	0.05	0.36	0.60	4.93	0.40	"
57	Wash Dickerson	38.27	54.68	30.86	0.06	0.29	0.09	0.34	0.70	4.60	0.32	"
59	Wm Boggs	37.33	53.33	29.32	0.035	0.32	0.12	0.28	0.70	5.15	0.36	"
60	Wm Boggs	33.87	48.30	32.93	none	0.66	0.09	0.50	0.65	6.17	0.40	"
	Hematite average	53.31		9.99	0.03	0.616	0.024	1.536			....	"
	Limonite average	37.925	.	29.595	0.033	0.35	0.088	0.354				"
	Total Average	40.37	.	20.68	0.033	0.47	0.059	0.89				

GRANT AND MINERAL COUNTIES.

Survey No	MINE OR PROSPECT	Metallic Iron	Iron Oxide	Silica	Manganese Dioxide	Phosphorus	Sulphur	Lime Oxide	Moisture	Loss on Ignition	Titanium Oxide	Kind of Ore
49	Ketterman	56.00	80.00	6.81	0.04	0.46	0.002	1.64	0.60	3.44	0.07	Hematite
33	Feaster	41.55	59.36	5.18	0.026	0.59	0.02	1.32	1.18	5.18	0.25	"
12	Greenland Gap	42.83	61.06	13.18	0.02	0.72	0.04	4.03	0.27	9.56	0.14	"
22	Alkire at Keyser	27.24	38.88	54.30	none	0.41	0.01	0.60	0.10	1.17	0.21	"
31	County Road, Keyser	32.65	46.64	48.88	0.03	0.19	0.004	0.16	0.25	1.50	0.21	"
	Average	40.05	.	25.67	0.023	0.474	0.015	1.55				

HARDY COUNTY.

Survey No	MINE OR PROSPECT	Metallic Iron	Iron Oxide	Silica	Manganese Dioxide	Phosphorus	Sulphur	Lime Oxide	Moisture	Loss on Ignition	Titanium Oxide	Kind of Ore
46	Baker Moorefield	41.46	63.52	8.30	0.035	0.48	0.019	10.35	0.50	10.75	0.07	Hematite
48	Burns Knob, Moorefield	52.70	75.28	13.81	0.04	0.26	0.007	0.22	0.14	9.71	0.01	Limonite
45	Fisher, Moorefield	53.14	75.92	10.48	0.035	0.15	0.001	0.46	0.24	10.14	0.07	"
81	Ruckman, Moorefield	31.96	45.65	34.41	...	....	..	.		...		"
31	Strausman, Lost River,	39.20	56.00	35.86	0.017	0.23	0.000	0.08	0.10	11.35	0.07	"
7	Wood, Lost River	50.96	72.80	12.44	0.47	0.41	0.023	0.40	0.27	8.83	0.18	"
35	Bear Wallow, Lost River	44.69	63.84	21.63	0.04	0.39	0.02	0.16	0.29	6.66	0.21	"
	Average	45.80	..	19.56	0.091	0.27	0.01	1.67				
38	Pee Dee Capon	47.40	68.00	27.02	1.66	0.28	0.008	0.10	0.30	10.40	0.11	"
17	Pee Dee, lower bed	47.94	68.48	16.82	0.02	0.22	0.02	0.24	0.46	10.80	0.21	"
34	Warm Spring Mine	55.55	79.36	5.59	0.30	1.46	0.01	0.20	0.30	11.96	0.07	"
37	Warm Spring Hill	40.54	57.92	19.66	0.30	1.86	0.01	0.25	0.29	10.21	0.25	"
8	Spring Knob	42.06	60.08	22.69	0.00	0.30	0.045	0.32	0.56	7.68	0.43	"
32	Bowers shaft	30.24	43.20	32.75	0.09	0.37	0.01	0.08	0.55	8.31	0.36	"
21	Sterrett mine	38.65	55.36	21.26	2.19	0.56	0.01	0.22	0.24	10.38	0.29	"
20	Half Moon, upper level	49.17	70.24	17.70	0.03	0.20	0.02	0.12	0.04	10.11	0.29	
2	Half Moon, lower level	42.22	60.32	22.16	0.00	0.20	0.05	0.66	0.24	9.13	0.22	"
21	Half Moon Mountain	54.58	77.97	3.03	0.017	1.10	0.01	0.25	0.90	13.09	0.07	"
28	Cold Short mine	38.08	54.40	23.84	0.06	0.71	0.12	0.44	0.54	11.67	0.36	"
27	White Metal mine	24.31	36.16	35.42	1.17	0.28	0.01	0.46	0.72	9.00	0.43	"
5	Mellon shaft	47.26	67.52	8.51	3.75	0.41	0.002	0.54	0.42	14.13	0.07	"
6	Rock Bank	58.66	83.80	3.51	trace	0.91	0.016	0.47	0.80	10.17	0.01	"
9	Flanagan road	39.20	56.00	22.39	2.53	0.49	0.023	0.25	0.30	9.65	0.29	"
39	Bear Pen	42.00	60.00	28.60	0.41	0.30	0.02	0.25	0.20	7.67	0.29	Hematite
10	Buck Thicket	21.47	35.96	39.34	0.13	0.03	0.01	0.20	0.80	5.93	0.50	"
4	Frye land	45.25	64.64	14.55	0.72	1.04	0.006	0.72	0.28	12.89	0.18	Limonite
14	Anderson Ridge	34.16	48.80	27.20	0.04	1.00	0.01	0.30	0.70	9.15	0.25	"
43	Lee tract	43.96	62.80	15.40	0.79	0.77	0.04	0.17	0.37	10.00	0.14	"
11	Bulinger Knob	42.89	61.26	21.03	0.00	0.48	0.03	0.14	0.38	10.54	0.21	"
11	Bens Hill	38.96	55.68	27.52	0.04	0.98	0.012	0.15	0.45	8.73	0.14	"
14	Bens Hill fossil	42.00	60.00	25.24	0.017	0.47	0.09	0.26	0.41	6.78	0.21	"
42	Seger, upper	41.05	58.64	15.18	2.12	1.22	0.02	0.20	0.50	11.02	0.29	"
29	Seger, lower	44.13	63.04	11.60	1.66	0.54	0.008	0.12	0.35	9.65	0.21	"
3	Five Mile mine	34.72	49.60	34.74	trace	0.14	0.01	0.58	0.22	7.73	0.21	"
19	Gochenour	40.10	57.28	20.58	0.50	0.66	0.012	0.16	0.43	10.52	0.21	
18	Finley	49.28	70.40	15.64	0.00	0.48	0.01	0.25	0.13	10.62	0.07	"
1	Baker Mountain	40.37	57.68	22.44	0.00	0.32	0.17	0.91	0.16	10.97	0.18	"
23	Farmer land	46.85	66.93	15.13	0.28	0.61	0.025	0.26	0.50	9.95	0.21	"
	Average	40.22		20.65	0.627	0.613	0.027	0.31				"
	County average	42.79		20.41	0.526	0.551	0.024	0.57				"

MONROE COUNTY.

Survey No	MINE OR PROSPECT	Metallic Iron	Iron Oxide	Silica	Manganese Dioxide	Phosphorus	Sulphur	Lime Oxide	Moisture	Loss on Ignition	Titanium Oxide	Kind of Ore
70	Crimson	47.44	67.82	20.02	trace	0.56	0.02	0.20	0.09	10.03	0.07	Limonite
72	Zenith	54.09	77.29	9.22	0.035	0.16	0.03	0.30	0.80	8.78	0.11	"
74	Epling	52.29	74.37	11.67	trace	0.81	0.01	0.21	0.11	9.67	0.07	Hematite
75	Peters Mountain	48.10	68.91	23.74	0.039	0.55	0.01	0.21	0.20	5.10	0.25	
71	Mark Patton	53.20	74.02	5.84	0.49	1.01	0.02	1.20	0.08	10.52	0.14	Limonite
69	Doss	51.38	73.54	10.43	0.02	1.06	0.02	0.30	0.23	11.85	0.07	"
68	Cowder	49.56	64.40	18.52	0.065	1.26	0.02	0.26	0.17	11.47	0.18	"
73	Rocksalia Spring	54.22	77.42	3.13	0.017	1.23	0.02	0.30	0.49	12.24	0.04	"
76	Peters Mountain	41.74	59.61	11.82	0.49	1.10	0.01	0.36	0.10	9.77	0.18	Hematite
	Average	50.22	....	12.74	0.128	0.86	0.017	0.37			..	

GREENBRIER COUNTY.

Survey No	MINE OR PROSPECT	Metallic Iron	Iron Oxide	Silica	Manganese Dioxide	Phosphorus	Sulphur	Lime Oxide	Moisture	Loss on Ignition	Titanium Oxide	Kind of Ore
67	Fertig	58.23	83.19	4.56	0.035	0.61	0.07	0.24	0.27	7.53	0.36	Limonite
65	Perry	59.23	84.67	7.24	0.02	0.19	0.22	0.21	0.23	5.02	0.07	
64	Dan	58.93	84.22	2.01	0.02	0.72	0.02	0.20	0.19	11.26	0.07	
66	Monument	36.77	52.54	37.26	0.02	0.92	0.02	0.22	0.10	5.92	0.07	"
63	Little Creek	55.59	76.57	9.40	0.02	0.61	0.02	0.22	0.30	10.50	0.07	"
	Average	53.35	......	12.094	0.023	0.61	0.07	0.224				

JEFFERSON AND BERKELEY COUNTIES

Survey No	MINE OR PROSPECT	Metallic Iron	Iron Oxide	Silica	Manganese Dioxide	Phosphorus	Sulphur	Lime Oxide	Moisture	Loss on Ignition	Titanium Oxide	Kind of Ore
78	Harpers Ferry	41.21	58.87	20.75	1.40	0.31	0.02	0.26	0.27	10.03	0.21	Limonite
79	Harpers Ferry (washed)	44.14	63.05	19.70	0.39	0.28	0.03	0.30	0.10	9.88	0.05	"
80	Martinsburg	38.63	55.17	35.98								"
	Average of State	43.86	..	19.48	0.328	0.56	0.031	0.62				70 Samples

purposes; but open-hearth steel should be used for railway bridges, boilers, locomotive forgings, and other purposes where the steel is subject to vibration and shock.

With the increase in demand for and production of open-hearth steel, the West Virginia non-Bessemer ores will become important, and they are even now attracting the attention of capitalists.

QUALITY OF THE WEST VIRGINIA IRON ORES.

The adjoining table groups together the analyses of West Virginia iron ores as made in the Geological Survey Laboratory by L. Patton assistant chemist working under the direction of Prof. B. H. Hite chief chemist.

The metallic iron in these ores varies from 24.31 per cent in the White Metal opening on Capon Furnace tract in Hardy county to 59.23 per cent in the Perry prospect on Beaver Lick Mountain in Greenbrier county. The phosphorus is usually under one per cent, but reaches 1.86 per cent in the Warm Spring Hill ore in Hardy county. Manganese is usually small in quantity in these ores, but reaches 3.75 per cent in the ore at Mellon shaft in Hardy county. Sulphur and titanium are low in all the ores. The average of the 70 analyses is as follows:

Average of 70 Iron Ores in West Virginia.

	Per Cent.
Metallic iron	43.86
Silica	19.48
Manganese	0.328
Phosphorus	0.56
Sulphur	0.031
Lime oxide	0.62

IRON ORE RESERVES.

Prof. Tornebohm the Swedish geologist in 1904 made the following estimate on the iron ore tonnage of the world and the ore annually consumed:[3]

3. Quoted by Eckel in U. S. G. S. Mineral Resources for 1906.

Country	Workable deposits.	Annual output.	Annual consumption.
United States ...	1,100,000,000	35,000,000	35,000,000
Great Britain ..	1,000,000,000	14,000,000	20,000,000
Germany	2,000,000,000	21,000,000	24,000,000
Spain	500,000,000	8,000,000	1,000,000
Russia & Finl'd.	1,500,000,000	4,000,000	6,000,000
France....	1,500,000,000	6,000,000	8,000,000
Sweden...	1,000,000,000	4,000,000	1,000,000
Austria-Hungary	1,200,000,000	3,000,000	4,000,000
Other countries.	1,200,000,000	5,000,000	1,000,000
Total..	10,000,000,000	100,000,000	100,000,000

Mr. Eckel in commenting on this table states there is probably an error of over 1,000 per cent. His discussion of this subject is of great interest and gives an answer to the question whether there will be any demand in the near future for the lower grade ores such as are found in West Virginia. This discussion of Mr. Edwin C. Eckel, given in the report of the U. S. Geological Survey is quoted in the following paragraphs:

"The Lake Superior district, at present the leading American producer, has been explored more thoroughly than any other ore field in the United States, but estimates as to total tonnage range within rather wide limits. At present the totals commonly quoted vary from 1,500,000,000 to 2,000,000,000 tons, of which the United States Steel Corporation is commonly supposed to control over three-fourths. This supply is being drawn on to meet a constantly increasing annual demand, and it is conceded that before 1915 the district will probably be called upon to ship over 50,000,000 tons of ore a year. It is obvious that at such a rate the Lake Superior ores can hardly be expected to last beyond the year 1950, and it is equally obvious that long before that date the value of good workable deposits of iron ore, both there and elsewhere in the United States, will have increased im-

mensely. During the past year ore lands in the Lake district have been sold at a valuation of $1 per ton of ore in the ground, though the average valuation is still of course considerably below that price.

"In the Rocky Mountain and Pacific States a few large iron-ore deposits are known to exist, and many others are reported, but any attempt at an estimate of total tonnage would be, with only our present knowledge of the subject, merely the wildest sort of guessing.

"A more promising field lies in the older Eastern States. It is probable that careful exploratory work will develop magnetic iron ores in New York, New Jersey, and Pennsylvania in quantities far in excess of anything usually considered possible in those States. Here also close estimates are impossible.

"With regard to the southern iron ores the case is very different. Here the work which the Geological Survey has carried on during the last three years and which was planned so as to obtain data on the quantity of ore available, gives a fairly secure basis for tonnage estimates. It is safe, therefore, to submit the following figures as representing minimum values for the workable iron-ore reserves above the 1,000-foot level of certain Southern States, with the caution that further exploratory work in the South will probably greatly increase rather than decrease these estimates:

		Red ore.	Brown ore.
Alabama	long tons	1,000,000,000	75,000,000
Georgia	do	200,000,000	125,000,000
Tennessee	do	600,000,000	225,000,000
Virginia	do	50,000,000	300,000,000
Total	do	1,850,000,000	725,000,000

"This gives a total estimated reserve for the red and brown ores of the four States noted, of over 2,500,000,000 tons. If to this we add the ores occurring at deeper levels in the States named, and also the red and brown ores of Maryland, West Virginia, and Kentucky, and the magnetic ores of the other Southern States, it is probably fair to

assume that the total southern ore reserve will amount to very nearly 10,000,000,000 tons, or five times that credited to the Lake Superior district. Much of this ore is of course unworkable at the present day, but all of it should be counted on in any estimate of total ore reserves.

"In considering these figures it will be well to bear in mind that the southern red ores will average from 33 to 43 per cent metallic iron, but that they carry so much lime as to be almost quite self-fluxing. The brown ores, as washed, will range from 40 to 50 per cent metallic iron. It may be further added that the estimates as to red-ore tonnage are probably much more accurate than those relative to brown ores.

"To sum up the matter—in place of the 1,100,000,000 tons credited by the Swedish geologist, it is probably safe to say that the United States has from ten to twenty times that reserve of iron ore.

"The present rate at which our ore is being mined is as follows:

1903	tons	35,019,308
1904	do	27,644,330
1905	do	42,526,133
1906	do	47,749,728

"Assuming that the demand for iron ore during the present century may range from 50,000,000 to 100,000,000 tons per year, the Lake Superior district would last from twenty-five to fifty years more, if it supplied the entire United States. But counting on the known reserves elsewhere in the United States the ore will last for a much longer period, though, of course, it must necessarily show a gradual but steady increase in value and in cost of mining, along with an equally steady decrease in grade. No attempt is here made to consider a very important factor in the problem—the extent to which Cuban, Haytian, and other high-grade foreign ores may be imported in the near future."

Dr. William Kent in the article already quoted, states that the period of twenty-five years from 1880 to 1905 in-

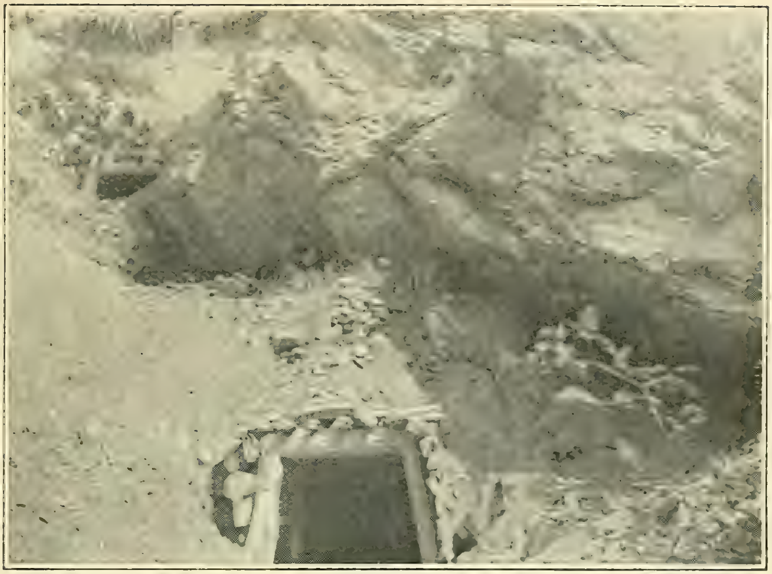

Plate IX.—A.—The Old Tunnels at the Dan Mine, Beaver Lick Mountain, Pocahontas County.

Plate IX.—B.—Hanging Wall at the Dan Mine, Beaver Lick Mountain, Pocahontas County.

cluding one large panic and two small ones, might be taken as representing average future conditions. The rate of increase in iron ore production during this period was 7.424 per cent per annum, or 104.742 per cent per decade. If the increase in iron ore production be taken at 100 per cent per decade, Dr. Kent estimates the future annual production as follows:

1910	33,000,000	tons
1920	66,000,000	"
1930	132,000,000	"
1940	264,000,000	"
1950	528,000,000	"

PART II.

Salt in West Virginia.

CHAPTER XI.

THE DISTRIBUTION AND ORIGIN OF SALT.

Common salt or sodium chloride (Na Cl) is one of the very common and also most important minerals, forming one of the necessities of life. When theoretically pure, common salt contains 39.59 per cent of sodium and 60.41 per cent chlorine. It occurs in solid form as rock salt with a hardness of 2.5 and a gravity of 2 to 2.2; and also in form of salt brines and in sea water and certain salt lakes. A saturated salt brine contains 26.46 per cent of salt, with a specific gravity of 1.205. It is found associated with the rocks of all geological ages from the earliest Paleozoic to the present. Its history antedates the earliest human records, and its use is as old as life. It is almost universally distributed, being found in practically all countries, and in every state of the Union. It is obtained on a commercial scale in 16 states whose production for 1906-7 is given in the following table in order of rank:[1]

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1. Taken from U. S. Geol. Survey, Mineral Resources for 1906, 1907.

Production and Value of Salt in the United States, 1906-7.

State	1906		1907		1906
	Quantity.	Value.	Quantity.	Value.	Av. Price per bbl.
	Barrels.	Dollars	Barrels	Dollars	Cents
New York	8,978,630	2,098,686	9,642,178	2,335,150	23.4
Michigan	9,936,802	2,018,760	10,786,630	2,062,357	20.3
Ohio	3,236,785	789,237	3,851,243	979,078	24.3
Kansas	2,198,837	681,022	2,667,459	962,334	31.0
Louisiana	1.179,528	268,005	1,157,621	226,892	22.7
California	806,788	291,528	626,693	302,940	36.1
West Virginia	200,055	57,584	156,147	76,527	28.7
Texas	360,733	170,559	356,086	226,540	47.0
Utah	262,212	169,635	345,557	199,779	64.6
Idaho	1,574	1,867	1,600	2,040	118.6
Nevada	11,249	6,420	6,457	3,654	57.0
Oklahoma	9,893	4,965	800	910	50.2
Other States	*a* 989,294	100,082	*b* 102,657	61,350	10.0
Total	28,172,380	6,658,350	29,704,128	7,439,551	

a. Includes Virginia, Pennsylvania, New Mexico and Massachusetts.

b Includes Pennsylvania, New Mexico and Massachusetts.

The average net price per barrel in New York in 1906, according to the above report was 23.4 cents; and in Michigan, 20.3 cents. Michigan and New York produced over two-thirds of the total, and the first five states above produced 90.62 per cent of the total.

A brief review will be given of the salt industry in the different states, the facts taken from Mineral Resources reports of the U. S. Geological Survey and from state reports.

New York. The salt of New York State is obtained from mining rock salt, evaporation of natural brines, and evaporation of artificial brines formed by running water through borinfs to the rock salt. In 1906 the producing localities in the state as given by the U. S. Geological Survey, were the Onondaga district in Onondaga county near Syracuse; at Cayuga and Ithaca in Tompkins county; Watkins Glen in Schuyler county; Perry, Rock Glenn, and Silver

Springs in Wyoming county; Le Roy in Genesee county: Geneseo, Retsof, Cuylerville, and Piffard in Livingston county.

The manufacture of salt[2] in the vicinity of Syracuse began in 1788 on a small scale, and in 1789 a 32 kettle plant was built using brine from shallow wells 30 feet deep. In 1878 rock salt was found in a well 1,279 feet deep in the town of Wyoming, Wyoming county, and the bed was 70 feet thick In 1881, an 80-foot bed of rock salt was found at Warsaw at a depth of 1,620 feet. In 1885, rock salt was found at Silver Springs and Rock Glen in Wyoming county. In September, 1885, a shaft 995 feet deep was completed to the rock salt at Retsof near Greigsville.

The salt deposits of New York occur almost entirely in the Salina or Onondaga Group of the Upper Silurian geological period. The wells are usually 1,000 to 1,300 feet deep. In 1893, there were four rock salt shaft mines in the state and over 100 producing salt brine wells. Near Syracuse the wells are 230 to 386 feet deep and the brine comes to within 18 to 22 feet of surface.

The following analyses by Englehardt in Mr. Merrill's report show the composition of a few of the New York brines. The low figures represent natural brines while the high figures apply to artificial brines which are made as nearly saturated as possible:

	Warsaw.	LeRoy.	Genesee. Valley.	Onondaga.	Brines.
Water	73.958	75.4796	73.99156	81.4246	80.0973
Sodium chloride	25.711	23.5819	25.33911	17.7673	19.0646
Lime chloride	0.135	0.5268	0.20260	0.1453	0.1693
Lime sulphate	0.443	0.3083	0.41391	0.5431	0.5141
Magnesium chloride	0.053	0.1034	0.05126	0.1197	0.1547
Specific gravity	1.2045	1.920	1.20114	1.1420	1.1486
Ferric oxide	not det.	not det.	0.00156	not det.	not det.

Michigan. Michigan produces a greater quantity of salt than any other state, but the total value is less than New

2. Based on report F. J. H. Merrill, Bull. No. 11, New York State Museum; 1893.

York. The rock salt is found in the Salina division of the Upper Silurian and also in the sandstones of the Lower Carboniferous. The wells are drilled to the rock salt and water pumped in, forming an artificial brine which is evaporated in pans usually by the Michigan grainer process. In some places it is used directly in the chemical works in manufacture of soda salts.

The producing areas in 1906 according to the report of the U. S. Geological Survey were: Ludington, Saginaw, St. Charles, Manistee, Filer City, Eastlake, Marine, Port Huron, Deliay (near Detroit), Wyandotte, Ecorse, Midland, and Bay City.

The composition of the Michigan brines is given in the following analyses:[3]

	E. Saginaw.	Saginaw.	Bay City.	Bay County.
Specific gravity	1.179	.....	.....	.....
Percentage of solids in brine	22.02	21.32	16.61	24.15
Solid matter in brine—				
Sodium chloride	81.38	82.14	91.95	82.24
Lime sulphate	0.53	0.46	2.39	0.30
Lime chloride	0.73	12.39	3.19	12.25
Magnesium chloride	6.91	5.01	2.48	5.22
Magnesium sulphate	....	.....	.....	.....
Alumina, silica and iron	0.48	.....	.....	.....

Ohio. This state held third rank in salt production in 1906, with salt obtained from evaporation of brines. The producing localities were: Pomeroy, Cleveland, Akron, Barberton, Durant, Rittman, and Wadsworth.

The first attempt to make salt on a commercial scale in Ohio was in 1789 at the old Scioto Salt Works on the banks of Salt Creek in Jackson county. Hildreth[4] states that these wells were 20 to 30 feet deep, and required 600 to 800 gallons of brine to make a bushel of dark colored salt which sold down to 1808 at $3 and $4 a bushel. In 1802, a salt reservation six miles square was made of this area by Congress for the use of the state. Two other tracst of 640 acres each were also reserved, one on Salt Creek in Muskingum county, and

3. Quoted by Eckel, U. S. G. S.. Bull. 213, p. 415; 1902.
4. Amer. Jour. Science (series 1), vol. 24, p. 46; 1833.

the other in Delaware county. An agent was appointed in 1804 to rent out small lots on these reservations to manufacturers at a rental of 16 cents a year per gallon kettle capacity, but no one person could use over 4,000 nor less than 600 gallons to each furnace. The average revenue never exceeded $500 a year, and in 1826 the salt reservations were sold and the money turned over to the state treasury.

The following notes on the Ohio salt operations are taken from J. A. Bownocker's bulletin on this subject.[5] In the Muskingum valley, drilling for salt began in 1817 near Zanesville, but was not very successful, later wells drilled to depth of 850 feet yielded a brine of which one gallon made a pound of salt, and by 1833 the production of the valley was 300,000 to 400,0000 bushels a year. This area has been abandoned, as also the salt industry in Columbiana, Tuscarawas, Hocking, and Guernsey counties.

In Morgan county near Durant on the Muskingum river, there is a single plant with daily capacity of 20 barrels using two pans with grainer process. The brine comes from the salt sand in two wells about 670 feet deep.

Meigs county was for many years the largest producing salt county and at present time is the most important area in southeastern Ohio. The industry centers at Pomeroy where it was developed in 1850. The maximum number of furnaces near Pomeroy and Middleport was 13 near close of the Civil War, and at present time there are only 4 or 5. With the decline in price of salt and the discovery of stronger brines in northeastern Ohio, the plants were mostly closed. The operating plants now depend for profit on the by-products of bromine and calcium chloride.

The wells are drilled to a depth of 1,000 to 1,590 feet, the latter depth reaching the Berea sand, while the other wells secure the brine from the Big Salt Sand of the Carboniferous. The daily capacity of the five plants at Pomeroy is 1,300 barrels from about 20 wells. Mr. Bownocker gives the following analyses of the Pomeroy brine. The analyses were

5. Ohio Geol. Survey, (series 4) Bull. No. 8; 1906.

made by C. W. Foulk in 1906 and in 1888 by Root. These analyses show the presence of bromine and high percentage of calcium chloride, as well as an absence of lime sulphate or gypsum which is characteristic of most American salt brines. The absence of the sulphates is usually explained by the presence of barium chloride which would precipitate such salts.

	Analysis. 1906.	Analysis. 1888.
Specific gravity	1.075	1.071
Sodium chloride	80.134	79.273
Calcium chloride	13.633	14.397
Magnesium chloride	5.314	6.097
Magnesium bromide	0.147	0.097
Sodium iodide	0.004	0.012
Silica	0.079	0.043
Iron and alumina oxides	0.011	0.082
Potassium chloride	0.108	......
Strontium chloride	0.244	......
Barium chloride	0.326	......

In northeastern Ohio at Wadsworth, rock salt was found at about 2,500 feet in drilling an oil well in 1890, and in 1891 a salt company was organized and began manufacture of salt in 1893. The brine is secured from the wells about 2,700 feet deep, in which the aggregate thickness of rock salt is said to be 140 feet. Fresh water is run into the wells and the saturated brine is pumped out and evaporated in vacuum pans with capacity of 1,200 barrels of salt daily.

At Rittman in Wayne county, salt was first made in the fall of 1898. The company has four wells about 2,625 feet deep. Fresh water is pumped into the wells and the resulting brine evaprated in two vacuum pans and seven grainers, with a daily capacity of 2,000 barrels. Near Cleveland there are two plants in operation. One has a daily capacity of 1,800 barrels with brine supplied by five wells from a depth of 2,000 feet. The other has three wells of about the same depth as the first, and uses two vacuum pans and four grainers, with a capacity of 90,000 tons a year.

At Kenmore near Akron, the brine is obtained from six wells with a depth of about 2,800 feet. Fresh water is

pumped into these wells and the brine is evaporated in two vacuum pans and fourteen grainers, with a daily capacity of 2,000 barrels. The salt horizon in these northeastern Ohio wells is the Salina Group of the Upper Silurian. Bownocker states that these artificial brines yield 2.59 pounds of salt to the gallon, while the Pomeroy yields only 0.70 pound to the gallon. There are 11 operating salt plants in the state of Ohio with a daily capacity of 10,320 barrels. According to the statistics of 1906, the total production that year was 3,236,785 barrels.

Mr. Bownocker gives the following analyses of the salt produced at a number of the Ohio plants:

	A.	B.	C.	D.	E.
Moisture	0.52	0.57	0.37	1.22	7.42
Sodium chloride	98.09	97.61	98.81	97.91	91.31
Lime sulphate	1.19	1.70	0.68	0.68	0.00
Lime chloride	0.20	0.12	0.14	0.08	0.95
Silica, iron, alumina	0.00	0.00	0.00	0.04	0.00
Magnesium chloride	0.00	0.00	0.00	0.07	0.32

A. Ohio Salt Co., Rittman.
B. Wadsworth Salt Co., Wadsworth.
C. Union Salt Co., Cleveland.
D. Union Salt Co., Cleveland.
E. Coal Ridge Co., Pomeroy.

The first three salts were made in vacuum pans, and the last two in pans by grainer process.

Kansas. The salt industry in Kansas depends on the rock salt found in Permian strata, and includes the mining of rock salt and evaporation of artificial brines formed by running water into wells drilled to the salt rock. The producing centers in 1906 according to the report of U. S. Geological Survey were: Hutchinson, Ellsworth, Kanopolis, Anthony, Sterling, Lyons, and Kingman. The rock salt was mined at Kanopolis, Lyons, and Kingman.

In 1876 salt brine was obtained from wells near Solomon, and evaporated by the sun's heat. A second solar plant was built in 1874, and these two plants were in operation until a few years ago. In 1887-88 in prospect drilling for oil and gas near Lyons, at a depth of 800 feet a deposit of

rock salt was struck which was over 300 feet thick, made up of salt veins and layers of shale. In 1890 a shaft was put down 1,065 feet to mine this salt and the mine produced an average of 30 tons daily. Another mine is in operation at Kanopolis 880 feet, and two mines, 810 feet deep at Kingman.

At Anthony, the salt rock was struck at 946 feet below the surface and continued for 400 feet. At Ellsworth the rock salt was found at 728 feet near close 1887 and a shaft started but not completed. About 1901 an evaporating pan plant was established and artificial brines used. A small plant has been in operation at Sterling since 1891 using the pan system.

The largest center of evaporated salt manufacture is at Hutchinson where the salt rock was discovered in boring for oil in 1887, at a depth of 500 feet the thickness being 350 to 370 feet.

Louisiana. Rock salt is mined in Louisiana at Petite Anse in the extreme southern part of the state. According to Mr. E. O. Hovey in U. S. Geological Survey mineral resources for 1905, the salt is worked in mines with rooms or galleries, 200 feet long, 75 feet wide, and 65 feet high without timbering. While small in area, the thickness is very great. A boring was made near the mines and on Jefferson Island, which reached a depth of 1,833 feet in pure rock salt without reaching the bottom of the deposit. The salt averages 99 per cent sodium chloride and is found in the Cretaceous.

California. Practically all the salt in California, the sixth state in rank in production, is obtained by solar evaporation of water from the ocean or bays. The producing localities in 1906 according to the U. S. Geological Survey were: Newark, Alvarado, Mount Eden, Haywards, Long Beach near San Diego, and in Marin county.

The following notes on the minor salt producing states are taken from the reports of 1905 and 1906 on mineral resources by U. S. Geological Survey:

The commercial salt of Texas comes mainly from Van Zandt and Anderson counties where salt is made from artificial brines from wells reaching the rock salt beds in Cre-

taceous strata. These brines are evaporated by sun heat or by grainer process. Much salt is used locally from salt lakes or saline springs scattered over the state. These lakes and springs becoming dry leave a crust of salt ¼ to 1½ inches thick which is raked up and hauled away.

In Utah salt is obtained by solar evaporation in shallow ponds at Saltair, near the shore of Great Salt Lake. The water from the lake is pumped into these ponds and when evaporated the salt is raked in piles and loaded in cars for shipment. In Nevada, the salt comes from Washoe and Churchill counties where it is made from brine by solar evaporation. The commercial salt in Idaho is found in Bannock county, where it is made by open pan process on a small scale. In New Mexico, salt is made from brine by solar evaporation. The Oklahoma salt comes from near Ferguson and is evaporated in open vats. The salt of Virginia is an artificial brine from rock salt deposits in Lower Carboniferous strata at Saltville. A portion of the salt is sold but most of it is used at the alkali plant which owns the wells. An analysis of the rock salt shows 99.084 per cent sodium chloride, 0.446 of lime sulphate, and 0.47 per cent alumina, silica, and iron. In Massachusetts, a small quantity of salt is produced by evaporation of sea water near Buzzards Bay. The Pennsylvania output is also small and comes from the vicinity of Pittsburgh. An analysis of this salt shows:[6]

Specific gravity	1.019
Percentage solids in brine	2.8
Sodium chloride	81.27
Calcium chloride	13.93
Magnesium chloride	4.80

ORIGIN OF SALT.

Common salt and gypsum or lime sulphate from which plaster of Paris is made have a similar mode of origin, and the two substances are often associated together. The leading salt states are also the leading gypsum states. The writer in his reports on the gypsum deposits for the State Surveys

6. Quoted by Eckel, U. S. G. S., Bull. 213, p. 415.

of Kansas and Michigan has discussed at some length the theories of origin. This discussion in so far as it relates to the origin of salt is here quoted as follows:[7]

The most generally accepted theory of origin of large deposits of gypsum and salt has been that they are evaporated from salt water lakes or arms of bays and seas cut off from the main ocean. This theory has been given for the Iowa, New York, Virginia, Michigan, and Kansas fields.

Examples of these changes can be found in the salt lakes and ocean gulfs and bordering seas at the present day. In southern Europe are excellent examples of the results of the evaporation of salt lakes, and in this country the best examples are seen in the Great Salt Lake and in the neighboring salt lakes of Utah and Nevada. Lake Bonneville in the Quaternary period of geological time covered an area of 19,570 square miles with a depth of 1,050 feet, and its waters were fresh. Through evaporation, its level was lowered below the place of outlet at the north, and its waters in the course of time became more and more saline. This evaporation has continued until the present remnant, Salt Lake, has less than 2,400 square miles of area with an extreme depth of 50 feet, and its waters almost a concentrated brine with specific gravity of 1.1. The total amount of salt in this lake water is 15 per cent, of which 11.8 per cent is common salt.

The waters of the Dead Sea afford another example of concentrated brine due to evaporation. In this water there is 26 per cent of salts, but differing in composition from the American lake. There is only 3.6 per cent of the common salt and 15 per cent of the magnesium chloride as compared with 1.5 per cent of this salt in the Great Salt Lake. The amount of gypsum in the waters of the two basins is nearly the same, 0.086 per cent. The composition is given in the following table:[8]

7. For further discussion of origin of gypsum and salt see University Geological Survey of Kansas, vol. V, pp. 76-83, 1899; Michigan Geological Survey, vol. IX, part 2, pp. 182-191; 1903.

8. Geikie Text Book of Geology, p. 383; 1885.

	Great Salt Lake.	Dead Sea.
Sodium chloride	11.8628	3.6372
Magnesium chloride	1.4908	15.9774
Lime chloride	....	4.7197
Potassium chloride	0.0862	0.8379
Magnesium bromide	....	0.8157
Lime sulphate	0.0858	0.0889
Potassium sulphate	0.5363	......
Sodium sulphate	0.9321	......
Water	85.0060	73.9232
	100.0000	100.0000

Ocean water according to the analyses of the Challenger Reports contains 3.5 per cent of mineral salts of which three-fourths is common salt, sodium chloride. Salt from the waters of the Atlantic shows the following substances and proportions, according to these reports:

	Per Cent.
Sodium chloride (common salt)	77.758
Magnesium chloride	10.878
Magnesium sulphate	4.737
Lime sulphate (gypsum)	3.600
Potassium sulphate	2.465
Lime carbonate	0.345
Magnesium bromide	0.217
	100.000

When sea water is cut off and evaporated, the gypsum is deposited after 37 per cent of the water is removed, and common salt only after the removal of 93 per cent. The normal order would be a deposit of gypsum and then a much heavier deposit of salt. But as 93 per cent of the water must be evaporated before the salt would be thrown down, the evaporation might go far enough for the deposition of gypsum, but not far enough for the salt, or the salt might be deposited and subsequently removed by solution. Gypsum deposits are more wide-spread in nature than salt, but they are usually thinner.

In most areas the quantity of salt is far greater than the amount found in the ocean water that would cover the area at reasonable depths. The present condition of the Mediterranean sea seems to aid in the explanation of the formation of such deposits.

The most complete study of the composition and the currents of the Mediterranean sea were made by Captain Nares and Dr. Carpenter in 1871.[9] They found the basin of this sea to be 6,000 feet deep, separated from the ocean at the straits of Gibraltar by a ridge 1,200 feet high. The water of the Atlantic outside the ridge had a specific gravity of 1.026. In the western part of the sea the gravity is 1.027, and at the eastern part of the sea it is 1.03. The proportion of salts in the ocean was 3.6 per cent, and in the Mediterranean is 3.9 per cent. Passing over the dividing ridge were two currents, one over the other. The upper was inflowing and the lower outflowing. The water of the basin is not concentrated enough to deposit salt and gypsum, but it is gaining in quantity of salt held in solution.

So it is thought that the water in the old seas or gulfs of Kansas [10] and Iowa[11] received additions of salt and gypsum by inflowing water and thus increased the thickness of the deposits. This theory is thought to explain the great thickness of the salt deposits at Stassfurt (1,000 feet), and at Sperenberg (3,000 feet) in Germany, which could hardly have been deposited except from a continuous supply of salt water.

Where gulfs are cut off from the main sea, evaporation will continue until the salts are deposited, and if the supply of salt water is renewed, a large deposit of salt will result. This feature of salt formation is illustrated by the present history of several small bays and lakes cut off in recent time from the Caspian sea.

Into the northern part of the Caspian sea[12] empty the Volga, Ural, and Terek rivers bringing in a large quantity of fresh water, so that the sea water in this portion of the sea is nearly pure, with a specific gravity of 1.009. This small amount of salt, according to Von Baer, is partially due to the

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9. Proc. Roy. Soc. vol. XX, p. 97, 414; 1872, quoted in Enc. Brittanica, vol. XV, p. 821.

10. University Geol. Survey of Kansas, vol. V., p. 138.

11. Iowa Geol. Survey, vol. 12, p. 123.

12. Von Baer, Bull. Acad. St. Petersburg, 1855-6, quoted in Enc. Brittanica, vol. V., p. 176.

fresh water brought in and also to the number of shallow lagoons surrounding the basin, each being a sort of natural salt pan. At Novo Petrovsk, a former bay of the main sea is now divided into a number of basins showing all degrees of saline concentration. One of these has deposited on its banks only a thin layer of salt, a second has the bottom covered with a thick crust of crystals, a third is a compact mass of salt, and a fourth has lost all the water and is a mass of salt covered with sand. On the other side of the sea in the peninsula of Apsheron are ten salt lakes from one of which 10,000 tons of salt are annually produced.

The concentration is seen on the greatest scale in the Karaboghay (Black Gulf) of the Caspian, whose nearly circular shallow basin is about 90 miles across, and almost entirely cut off by a long narrow spit of land communicating with it by a channel not over 150 yards broad and five feet deep. Through this passes a current with an average velocity of three miles an hour, accelerated by the western winds.

This current is due to the indraught produced by excessive evaporation due to the heat and winds from the surface of the basin, which at the same time receives but little return from streams. The small depth of the bar prevents a counter current of highly saline water into the sea. The current carries into the Black Gulf, according to Von Baer, 350,000 tons of salt daily. If the bar should be elevated and cut off the basin from the sea, the gulf would quickly diminish and become a salt marsh, later drying up and leaving a heavy salt deposit. North of this gulf over the Russian steppes are sands and marls intermingled with salt, representing former salt lakes now dried up.

Similar conditions to those outlined above in the Mediterranean and especially the bordering gulfs of the Caspian would explain the thick deposits of rock salt found in New York, Michigan, and northeastern Ohio, in the Salina rocks, and in the Permian rocks of Kansas. In many places the salt is found in the form of natural brines, with no trace of rock salt. In the Onondaga salt district of New York, the

brines are supposed to be formed by leaching of rock salt to the south, and flowing northward through an old river channel now filled with gravel and sand.[13]

Bownocker [14] regards the brines of the Pomeroy region in Ohio as once part of the ocean and states, "As the sand or gravel now composing the salt bearing rocks, was deposited on the ocean floor, sea water filled the spaces between the grains and pebbles and has since remained in that position."

There is no indication of any rock salt in this vicinity so that the brine either represents the original sea water, or the ocean water was evaporated leaving the salt in the pores and around the sand grains which later has gone into solution in water which has penetrated the salt bearing rock. Percolating waters reaching the horizon have lowered the strength of the brine so that it is far from saturation making weak brine as compared with the artificial brines where water is run into wells to the rock salt.

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13. Merrill, Bull. New York State Museum, No. 11, p. 19.
14. Ohio Geol. Survey (series 4) Bull. No. 8, p. 26.

CHAPTER XII.

THE HISTORY OF THE SALT INDUSTRY IN WEST VIRGINIA.

KANAWHA VALLEY.

Salt making was one of the earliest industries in West Virginia. The first well was bored for salt[1] on the Big Kanawha (Kenhawa) river six miles above Charleston, to a depth of 70 or 80 feet finding a weak brine which required 400 gallons to make one bushel of salt (50 pounds). Later the wells were drilled to a depth of 350 feet yielding a stronger brine of which 75 gallons were required to make one bushel of salt. The salt area extended 12 to 14 miles along the Kanawha from a point 70 miles above its mouth.

Hildreth describes the salt rock as a white calcareous sand rock full of fissures and cavities, some inches in diameter. The annual production of salt for a number of years preceding 1833 was a million bushels, with no apparent decrease in supply of brine. He gives the following analyses of the Kanawha brine and bittern in parts per 1000:

	Brine.	Bittern.
Sodium chloride	56	93
Lime chloride	35	335
Iron carbonate	2	39
Carbonic dioxide	1	...
Water	906	511
Potash	...	22
	1000	1000

1. Following notes from Hildreth, Amer. Jour. Science (series 1), vol. 24, p. 46; 1833.

Hildreth states that the production of salt from Kanawha plants in 1833 was 1,200,000 bushels annually. He finds that one pint of this brine weighs 1 pound, 2 ounces, 44 grains, while the river water weighs 1 pound, 1 ounce. This would require 91 gallons of brine to make a bushel of salt. A plant of 30 or 40 kettles required daily 5 to 6 cords of wood. These kettles held 60 to 90 gallons each, set over a stone flue sunk in the earth so as to bring the tops of the kettles nearly on level with soil surface. The pan method of evaporation was also in use.

Dr. J. P. Hale, one of the early salt manufacturers in the Kanawha area, wrote a very complete account of the early history of the salt industry, based on his personal recollections and conversations with other early workers. This interesting article was printed in the 1876 Centennial book on Resources of West Virginia, and a large portion of the chapter was reprinted in the Oil and Gas Report (vol. 1-a) of the Survey. Those interested in the complete paper can find it in the 1876 volume, pages 274-305. The portion of this paper already quoted in the Survey reports will be repeated only in condensed form, as given in Dr. Hale"s chronological list as follows:

1753. Indians made salt at the Kanawha salt springs. Reported by Mrs. Mary Ingles, then a captive.

1774. Walter Kelley and family, first white settlers in Kanawha Valley.

1775. General Washington reserved from his lands, and gave to the public, the Kanawha Burning Spring.

1785. John Dickinson "located" the Kanawha Salt Spring.

1790. (Before and after) Daniel Boone lived here opposite the Salt Spring.

1794. Joseph Ruffner purchased the Salt Spring, and in 1795, moved to Kanawha.

1797. Elisha Brooks put up a little kettle furnace, and made 150 pounds of salt per day, and sold it at 8 to 10 cents per pound.

1806. David and Joseph Ruffner, commenced to bore the first salt well.

1808. Same parties started their kettle furnace, made 25 bushels per day, and sold it for 4 cents per pound.

1808. Wm. Whittaker, Tobias Ruffner, Andrew Donnally, and others followed, boring wells and building furnaces.

1808. First salt shipped west by river, in tubs and boxes on a log raft, and in canoes.

1810-12 The late Tom Ewing, of Ohio, boiled salt and studied law and Latin here.

1815. First gas well struck by Captain James Wilson.

1816. First steamboat ever in Kanawha, called the Eliza.

1817. Coal first used in salt making.

1817. The first Kanawha salt company, "Steele, Donnally & Steele."

1822. Highest water ever known in Kanawha to that time.

1822. Second salt company, "William and Robert M. Steele."

1827. Lewis Ruffner and Frederick Brooks introduced the first steam engine to pump salt water.

1827. Third salt company, "Armstrong, Grant & Co."

1830. F. Brooks laid the first wooden tramway to haul coal.

1831. Billy Morris invented the "Slips."

1833. Fourth salt company, "Donally, Bream & Co."

1834. Col. B. H. Smith brought from the Norfolk navy yard, model for keyed clamped cistern.

1835. Geo. Patrick introduced steam evaporation in salt making.

1835. Lewis Ruffner built the first keyed cistern (20 by 7 feet), and put a cast iron pipe through it.

1836. Fifth salt company, "Hewitt, Ruffner & Co."

1841. John D. Lewis first used steam under copper pans for making salt.

1841. Frederick Brooks first used copper pipes and steam through cistern.

1843. Big Burning Spring gas well struck.

1849. Williams & Stevens bored and built first furnace on the Ohio.

1851. Sixth salt company, "Ruffner, Donnally & Co."

1856. Seventh salt company, "Ruffner, Hale & Co."

1856. Lowest water ever known on the Kanawha and Ohio rivers.

1856-7 Coldest winter and longest freeze-up ever known here.

1861. Disastrous flood in river, the highest water ever known here.

1864. Eighth salt company, "Kanawha Salt Co."

1872. The Chesapeake and Ohio Railroad opened.

1875. The ninth and present salt company, "The Kanawha Salt Co.," organized.

1875. United States Government commenced to improve the Kanawha river by locks and dams.

It is thus seen that while salt was made in the Kanawha valley on a small scale in 1753, the real industry began with the work of the Ruffners in 1806 and 1808, and the first salt company was organized in 1817 using coal as fuel. In 1835 steam was used in the evaporation of the brines.

Dr. Hale in his original article describes the progress in method of manufacture and gives many interesting statistics of the early industry. Since this portion of his paper has not been reprinted in the Survey reports, it was thought advisable to include these sections in the present report.

"After the introduction of steam power, and the use of coal for fuel, no striking change was effected in the process of salt manufacture for a number of years. What improvements were made were simply in degree. Wells were bored deeper, and holes were bored larger, the tubing was better, the pumps and rigging simpler. The furnaces were larger, better constructed, and more effectively operated, the quality of the salt improved and the quantity increased, but still they were kettle furnaces of the original type

"The mammoth of the kettle era was that of Joseph Friend & Son, at the mouth of Campbell's creek, on which they made 100,000 bushels per annum. The usual capacity of other furnaces was 25,000 to 50,000 bushels per annum. This was about the condition of the salt manufacture here in 1835, when there were, all told, about 40 furnaces, producing annually about 2,000,000 bushels of salt.

"During this year (1835) George H. Patrick, Esq., of Onondaga, New York, came here to introduce a patent steam furnace. The furnace proper, after it was developed and improved, consisted of cast iron pans, or bottoms, 8 to 10 feet by 3 feet. Eight or ten of these pieces were bolted together by iron screws, forming one section 24 to 30 feet long, by 8 or 10 feet wide. There were two, three, or four of the sections according to the size of the furnace. Over each of the sections was constructed a wooden steam chest, bolted to the flanges on the sides of the pans, and otherwise held together by wooden clamps and keys, and iron bolts and rods, all made steam and water tight by calking. These several sections are set longitudinally on the furnace walls to form one continuous furnace.

"After the furnace comes a series of wooden vats or cisterns, a usual size for which, is about 10 feet wide and 100 feet long. The number of these cisterns varies according to the size of the furnace. They are constructed of poplar plank, 4 to 5 inches thick, dressed to joints, and fitted in a frame of oak by sills and clamps. They are tightened by driving wooden keys, and then calked to make them water tight. This system of clamping and keying cisterns was introduced here from a model brought by Col. B. H. Smith, from the navy yard at Norfolk. It was very simple and effective, and has been retained to this day, without improvements or change.

"There are two sets of these cisterns, the first in which the brines after boiling in the furnace proper, are settled, and at the same time strengthened up to saturation. The latter, in which the salt is graduated from the clear saturated brines. These settling and graining cisterns are very much alike, except that the grainers are but 15 to 18 inches deep, while the settlers may be double that or more. Through each and all of these cisterns from end to end are three rows of copper pipes, usually 5 inches in diameter.

"After the salt water is boiled in the furnace proper, it runs into these settling cisterns, and after being thoroughly settled and saturated, is drawn into the grainers, where the salt is deposited, and once in 24 hours is lifted out by long

handled shovels, on to a salt board, suspended above the grainer, and from which, after proper draining it is wheeled in wheel barrows to a salt house, where it is packed in barrels ready for shipment.

"The steam generated by the boiling in the furnace proper, is carried from the steam chest, by wooden pipes, to the copper pipes and through the settlers and grainers. This steam giving up its heat in passing through these cisterns, keeps up the temperature of the brines, and causes rapid evaporation. The temperature of these cisterns varies from 120° to 190°, an average would probably be 165°.

"This in short, is a description of the steam furnace, after it was improved, and the first mistakes and crudities eliminated. In the first experiments only very slight heat was imparted by the steam to the brines, and only coarse or alum salt made. It is very simple, accomplished all that was expected, and so soon as it was fairly tested, improved up to its working condition, and its advantages demonstrated, the days of the kettle furnaces were numbered.

"Andrew Donnally and Isaac Noyes were the first to try and adopt the plan. Then followed John D. Lewis, Lewis Ruffner, Frederick Brooks, and others, till all had made the change; and when the Ohio river furnaces were built the system was fully adopted there. It is now about 40 years since George Patrick introduced the steam furnace, but it still holds its position securely, and without a rival.

"Minor improvements have been made, and the furnaces much enlarged, but the general plan has not been changed. From the 2,000 or 3,000 or 4,000 bushels per month of the earlier furnaces, the production has increased to 20,000, 30,000 or 40,000 bushels per month. The writer's furnace, Snow Hill, has made in one year, independent of all stoppages, delays, etc., 420,000 bushels, the largest single month's run being 41,000 bushels. This furnace has 20,000 square feet of evaporating cistern furnace, and over 1,300 square feet of evaporating cistern surface, and over 1,300 bushels of coal per day are consumed in the furnace proper, and about 300 more for engines, houses, and other purposes.

"How far this will be exceeded in the future remains to be seen. The same progress has occurred in freighting salt, as in the manufacture. In the days of Elisha Brooks, the neighbors took the salt from the kettles in their pocket handkerchiefs, tin buckets, or pillow cases. Later,, it was taken in mealbags, on pack-horses, and pack-saddles.

"The first shipment west, by river, was in 1808, in tubs, boxes, and hogsheads, floated on a raft of logs. Next came small flat-boats, 50 to 75 feet long, and 10 to 18 feet wide, "run" by hand, and in which salt was shipped in barrels. These boats increased in size up to 160 feet or more long, and 24 to 25 feet wide, and carried 1,800 to 2,200 barrels of salt.

"These boats were all run by hand, at great risk, and although the Kanawha boatmen were the best in the world, the boats and cargoes were not unfrequently sunk, entailing heavy loss upon the owners of the salt. The late Col. Andrew Donnally used to ask, when he heard of one of his boats sinking whether any of the boatmen were drowned; if not, he contended it was not a fair sink. But now all this is done away with. Salt is now shipped eastward by rail, and to the nearest westward markets by daily and weekly steamboat packets, and to the more distant markets by towboats and barges. A towboat will now take 8,000 to 15,000 barrels at one trip, landing them at Louisville, Evansville, Nashville, Memphis, St. Louis, or elsewhere.

"In the matter of packages, no change has occurred here since the first use of barrels, the principal change being a gradual improvement in the quality of the cooperage. Our neighbors in Mason county, ship some salt in bulk, and some in bags, but the larger portion in barrels. Kanawha uses barrels exclusively. We use two sizes—280 pounds and 350 pounds net salt, respectively. The pork packing trade takes the larger size, and the retail trade, the smaller chiefly. These barrels are made of white oak staves and hickory hoops, and it is believed that nothing cheaper or better can be devised for salt packages. They are cheaper than bags, more convenient to handle, more convenient to store, stand rougher usage, and

more exposure to the weather. Markets having choice of salt in bags or barrels, generally prefer the barrels.

"In the earlier times of salt making here, various substances were experimented with for the purpose of settling or separating the impurities from the brine. Blood, glue, jelly, lime, alum, etc., were used. Something of the sort was necessary when the brine was boiled down in kettles with all its impurities, but they are all useless, and worse than useless in the present process, and have long been abandoned. Plenty of settle-room and plenty of time are all that are needed to have the brines as clear as spring water. The bitterns, after the salt is granulated, are thrown away, or used for other purposes. It has long been known that a small portion of some greasy or oily substance, on the surface of the brine helped "to cut the grain," and hasten the granulation. Butter, tallow, lard, rosin, oils, etc., have been tried. Of these, butter is far the best, and next to butter, tallow; lard and some of the others are positively detrimental.

"What the action of butter is, whether chemical or mechanical or both, I think has never been determined, but certain it is, that a very small quantity of butter on the surface of brine, while it is granulating very much improves the salt, making the grain finer and more uniform. Heat, too, is an important condition in making fine salt. The higher the temperature, other things being equal, the finer the salt. In making the finer grades of table and dairy salt, it is necessary to have the brine up to, or near, the boiling point. On the other hand, the coarser grades of salt, preferred for meat packing and other purposes, are made at temperatures of from 100° to 150° F.

"A still coarser grained, or larger crystallized salt, known as alum salt or solar salt, and made in the open air by solar evaporation, is not made here, but there is no reason why it should not be to great advantage, as we have longer summers and warmer suns than at Onondaga, New York, where it is very largely made, and with more profit than other grades of salt. Some of the waste products from salt making are recently being utilized. Mr. Lerner, an enterprising German,

is manufacturing bromine, both here and at the Mason county furnaces, from bitterns, and Mr. Bemmelmans, a Belgian chemist, is erecting works to manufacture hydrochloric acid from bitterns, and pigments from the impalpable oxide of iron which is deposited from salt brines.

"The cost of manufacturing salt on Kanawha varies, of course, from time to time, with the varying price of living, labor and supplies. It also varies with each particular furnace according to size, and the greater or less advantages which it posseses. The larger the furnace, other things being equal, the cheaper it will make salt. The general superintendence and management of a large furnace, costs very little, if any more, than for a small one; and a given quantity of coal will make more salt on a large furnace than a small one. The best furnace will make 100 bushels of salt with 80 to 90 bushels of coal. A good average result is, a bushel of salt for a bushel of coal, and the least economical consume about 125 bushels of coal per 100 bushels of salt.

"Some of the furnaces mine their own coal, and some buy fine nut coal from mines that are shipping coal. Even the best furnaces do not use coal at all economically or to the best advantage. There is, in this respect, great room for improvement. The cost of coal delivered at the furnaces, ranges from 2¾ to 4 cents per bushel. The present cost of barrels is 25 to 28 cents for the smaller size and 28 to 32 cents for the larger. The cost of common day labor is $1.00 to $1.25 per day. Coal miners get 2 cents per bushel. The cost of producing salt at these figures may be stated at 8 to 11 cents per bushel in bulk, or 13 to 16 cents in barrels, ready for shipment.

"The present cost of boring a salt well here, say 1,000 feet, after engine, well frame, &c., are ready, is $1,200 to $1,500. The time necessary to bore and ream it complete, is 60 to 90 days. The cost of a salt furnace, complete, depends upon size, &c., and varies within wide limits. It may be stated roughly at $40,000 to $100,000.

"The people of the United States consume more salt than those of any other country, the estimated average consumption being one bushel of 50 pounds per capita, for the entire

population. The great western markets, where our product goes, consume even more largely than the general average, as this is the largest pork-packing region on the globe. This portion of the country is rapidly increasing in population, and as rapidly in its meat crop and salt consumption.

"It is well known to chemists that salt is a valuable fertilizer on most soils for wheat, cotton, grass, potatoes, turnips, and other crops; and as an ingredient in compound manures it has a wide range of value. It is often recommended by the highest authorities, but, as yet, very little is so used in this country. When agriculture gets to be better understood and practiced, and agricultural people understand their interests better, a large demand and consumption will doubtless be developed in that direction.

"The most important and prospectively promising development in the manufacture of salt here, is its probable use on a larger scale in the manufacture of alkalies and other chemicals having salt as a basis or important constituent. * *

"The salt when carefully made, analyzes 98.00 to 99.00 per cent of pure chloride of sodium, the remaining fraction being made up of chlorides of magnesium and calcium. These absorb a little moisture from the atmosphere, relieve the salt from a chappy dryness, and impart to it that valuable property of penetrating and curing meat in any climate or weather, for which it has so long enjoyed a high reputation. In fact the distinctive characteristics of Kanawha salt may be stated as follows:

1st. It has a more lively, pungent and pleasant taste as a table salt than any other known.

2nd. It is the only commercial salt that is absolutely free from sulphate of lime.

3rd. It does not, under any conditions of climate and weather, cake or crust on the surface of the meat, but penetrates it and cures it thoroughly to the bone, so that in large pork packing establishments in Cincinnati and elsewhere, it is found to save meat in very unfavorable weather, where with any other salt known or used the meat would have been injured.

4th. On account of its pungency and penetrating qualities a less quantity of it will suffice for any of the purposes for which it is used—whether table, dairy, grazing or packing. Certificates from numerous western firms show that the Mason county salt quotes with this; though at the same price consumers prefer that from the Kanawha wells.

"There are in this salt district, about 120 salt wells, all told. Some of these being inferior, have been abandoned, and will probably never be used again. Others are good wells, the furnaces connected with which, have been dismantled by "dead rents," or other causes. These furnaces may be rebuilt, and restarted. The good wells, if all run, would supply brine for about 5,000,000 bushels of salt per year. Each furnace requires three to five wells.

"There are at present (1875) ten furnaces here, of which the following is a list, with name of furnace, name of owner, and capacity. The aggregate capacity is about 2,500,000 bushels per year, if all were run full time. Two of the furnaces, however, are not in repair, and some others that had been idle, have only recently been repaired, so that the product of 1875 was very small.

LIST OF KANAWHA SALT FURNACES. ....

Name of Furnace	Name of Owner	Productive Capacity Annually.	Remarks
Daniel Boone ..	W. B. Brooks........	300,000	
Crittenden	W. D. Shrewsberry...	280,000	Not in repair
Snow Hill	J. P. Hale	420,000	
Washington	J. D. Lewis..........	230,000	Not in repair
Pioneer	Gen. L. Ruffner	180,000	
Quincy	J. Q. Dickinson	210,000	
Burning Spring..	Mrs. R. Tompkins....	160,000	
Alden	Mrs. S. Dickinson....	240,000	
Lorena	Splint Coal Company..	240,000	
Kenton	Splint Coal Company..	240,000	
Total........	....	2,500,000	

Statement Showing the Production of Salt in Kanawha.

Date	Bushels.	Date	Bushels.
1797	150 lbs. per day.	1850	3,142,100 bu. per yr.
1808	25 bu. per. yr.	1851	2,862,676 bu. per yr.
1814	600,000 bu. per yr.	1852	2,741,570 bu. per yr.
1827	787,000 bu. per yr.	1853	2,729,910 bu. per. yr.
1828	863,542 bu. per yr.	1854	2,233,863 bu. per. yr.
1829	989,758 bu. per yr.	1855	1,493,548 bu. per yr.
1830	906,132 bu. per yr.	1856	1,264,049 bu. per yr.
1831	956,814 bu. per yr.	1857	1,266,749 bu. per yr.
1832	1,029,207 bu. per yr.	1858	No records.
1833	1,288,873bu. per yr.	1859	No records.
1834	1,702,956 bu. per yr.	1860	No records.
1835	1,960,583. bu. per yr.	1861	No records.
1836	1,762,410 bu. per yr.	1862	No records.
1837	1,880,415 bu. per yr.	1863	No records.
1838	1,811,076 bu. per yr.	1864	1,300,991 bu. per yr.
1839	1,593,217 bu. per yr.	1865	861,973 bu. per yr.
1840	1,419,205 bu. per yr.	1866	1,275,017 bu. per yr.
1841	1,443,645 bu. per yr.	1867	1,321,066 bu. per yr.
1842	1,919,389 bu. per yr.	1868	1,528,282 bu. per yr.
1843	2,197,887 bu. per yr.	1869	1,822,430 bu. per yr.
1844	1,874,919 bu. per yr.	1870	1,721,963 bu. per yr.
1845	2,578,499 bu. per yr.	1871	No records.
1846	3,224,786 bu. per yr.	1872	No records
1847	2,690,087 bu. per yr.	1873	No records.
1848	2,876,010 bu. per yr.	1874	No records.
1849	2,951,492 bu. per yr.	1875	967,465 bu. per yr.

MASON COUNTY.

The second district at Mason and Hartford City in Mason county on the Ohio river nearly opposite Pomeroy, Ohio, was developed later. The early history of the Mason county development is also given by Dr. J. P. Hale in the Centennial Report on Resources of West Virginia, 1876 (pp. 275-277) which is reproduced in the following sections:

"In 1849 Messrs. Williams and Stevens, aided by Capt. Tom Friend, all Kanawha salt makers, bored for salt water at West Columbia in Mason county on the Ohio river. They succeeded at about 700 feet in getting a fine well of water of good strength, and at once proceeded to erect the first Salt furnace on the Ohio river; they also bored several other wells

in the vicinity, none of which, however, proved so good as the first. They, shortly after, sold the property to New York parties who remodeled and rebuilt the furnace on a much larger scale, giving it a productive capacity of some 1,200 bushels, or more per day. The success of this enterprise gave a great impetus to salt boring, and coal mining throughout the available coal frontage of this region. This developed coal frontage along the river extends from West Columbia to Hartford City about 7 miles. Up the river the coal dips, until it passes under water level at, or just above Hartford City.

"The second salt furnace was erected at this upper limit of the coal frontage in 1854 by a Hartford City (Conn.) company, then under the management of W. O. Healy, Esq; since and now under the management of G. W. Moredock, Esq.—who has three large furnaces, with abundance of good brine, and cheap and convenient coal. These two operations, one at the extreme upper limit of the coal frontage,, demonstrated pretty clearly the existence of good brines throughout that extent, and at once gave a value to furnace sites and coal lands which the owners had not hitherto suspected them to possess.

"In 1855 Mr. R. C. Lovell, another Kanawha salt manufacturer, bored wells and erected a large furnace about half way between the two points above named, and laid out a town which he called "Mason City." This valuable salt and coal property was afterwards purchased by L. H. Sargeant of Cincinnati, O., and more recently has passed into the hands of Messrs. Roots & Kilbreth of the same city.

"Following these three furnaces, and within the next few years, were built the New Castle, Burnup, Clifton, Bedford, Hope, German, Jackson, Valley City, Starr and New Haven City, in all 13 in number. These 13 furnaces have a present productive capacity of over 3,000,000 bushels per year.

"The usual depth to which the wells in this neighborhood are bored, is about 1,100 to 1,200 feet; the strength of brines 8 to 10; the quantity, 15 to 50 gallons per minute per well. The wells are tubed with iron tubing, usually about 4

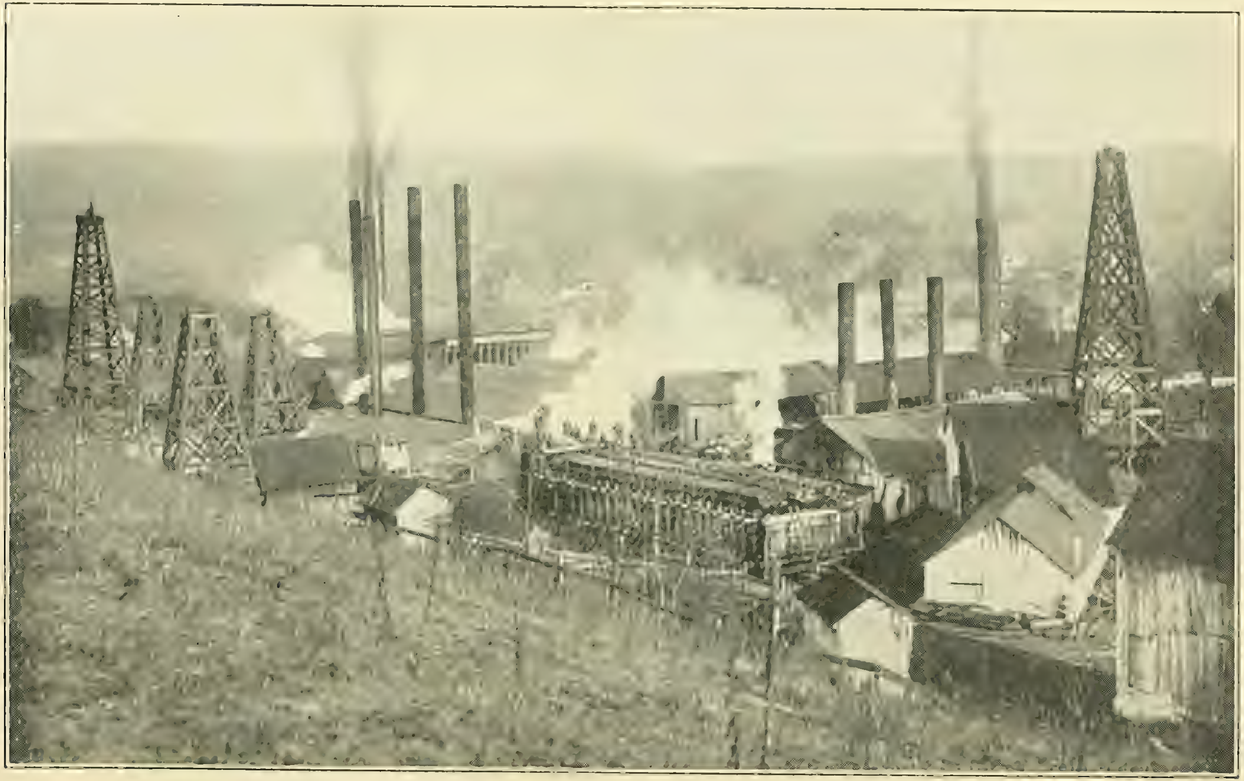

Plate X.—Plant of the Liverpool Salt and Coal Company at Hartford City, Mason County.

inches internal diameter, and bagged at 600 to 800 feet depth, at which depth the pumps were worked, run by steam power.

"The coal used here in the manufacture of salt, and also shipped to a considerable extent to the lower markets, is, geologically, the same as the well known Pittsburgh seam, so extensively mined and shipped near the city of that name. It is here a fine seam of coal, 4½ to 5 feet thick, easily mined, accessible and cheap.

"From the natural advantages of this locality, salt is produced here very cheaply, and cheaply freighted to the markets of the west, where it is in ready demand and its reputation deservedly excellent. From the bitterns or waste liquors from the salt furnaces here, a considerable quantity of bromine is manufactured, the uses and demand for which are steadily increasing. Chloride of calcium is also manufactured to some extent from these waste, bitter waters.

"The following table, kindly furnished by G. W. Moredock, Esq., of Hartford City, the largest manufacturer in Mason county, gives a very clear understanding of the present status of the salt manufacture in that county:

SALT WORKS, MASON COUNTY, W. VA.

Name of Furnace	Capacity.	Depth of Wells:	Owners' Name.
	Bushels.	Feet.	
New Haven	300,000	1,200	Hartford City Coal & Salt Co., 1,100 acres of coal land.
Hartford City	300,000	1,150-60	
Star	325,000	1,150-60	
Valley City	350,000	1,125-35	Val. City Coal & Salt Co.
Jackson	200,000	1,120-30	V. B. Horton, Jr.
German	250,000	1,120-30	German Salt Co.
Hope	350,000	1,120-30	Hope Salt Co.
Mason City	325,000	1,120-30	Mason City Salt Co.
Bedford	300,000	1,150	Bedford Salt Co.
Clifton	300,000	1,50	Not running.
Burnup or Quaker City	150,000	1,50	Not running.
New Castle	250,000	1,155	Not running.
West Columbia	300,000	1,125-40	Not running.
Actual capacity	3,700,000		
Actually made in 1875	2,500,000		

"It takes one bushel of coal to make a bushel of salt. Strength of brine from wells at Hartford City, 9 to 10, measured by Baume's salometer; Saturated brine 25, making the brine stand 40 per cent salt. (G. W. Moredock)."

CHAPTER XIII.

THE TECHNOLOGY OF SALT MANUFACTURE.

While most of the salt in United States is obtained by evaporation of brines, a certain quantity is obtained by mining of rock salt. The processes of salt manufacture may be grouped under the following heads:

1. Mining of rock salt.
2. Solar evaporation.
3. Direct fire evaporation.
4. Steam evaporation.
5. Vacuum pan evaporation.

1. MINING OF ROCK SALT.

In 1906 the total salt production of the United States was 28,172,380 barrels, of which 4,873.526 barrels were rock salt according to the U. S. Geological Survey.

In New York state[1] the rock salt mine shafts are 12x18 to 24 feet square, well timbered and cemented to shut out water. At the bottom of the shaft a main entry or gallery is driven from which rooms are worked 30 feet square with 30-foot square pillars of salt left to support the roof. The best portion of the vein is selected for working leaving 5 or 6 feet for roof and 4 feet for floor, so that the rooms in these mines are 14 feet high. Holes are drilled four to six feet into the salt above and blasted down with dynamite exploded by electricity, bringing the salt down in lumps or blocks in large quantity.

1. Englehardt, New York State Museum, Bull. No. 11, p. 36.

The larger blocks are broken by sledges and loaded into two ton mine cars which are pushed to the bottom of the shaft and hoisted to the top of the salt works. The salt blocks are then dumped into breakers and broken into small pieces which pass down over a series of screens separating it into the different commercial sizes. In the Kansas mines nine sizes are separated and sold. The larger and more impure lumps weighing 5 to 50 pounds are used by the stockmen for cattle, the lumps being placed out in the open fields where they will remain some months. A very pure grade of small cubes three-fourths inch square is obtained by hand picking by boys and girls selecting the pure and uniform size crystals, throwing aside discolored cubes. This grade is sold as capping-salt being placed in the bottom and top of barrels of pork and beef for exportation. The large packing houses of the west secure this grade from the Kansas mines. The next grade of salt cubes, a fourth to a half inch, is used in refrigerator cars, using about 500 pounds to the car. Other smaller sizes and the crushed salt are used for salting hides, manufacture of soda ash, and caustic soda, for ice cream manufacture, salting meats, etc. The finest salt is sold for domestic uses, but is not in as good demand as evaporated salt.

2. SOLAR EVAPORATION.

Where salt is made by evaporation of sea water in salt lakes, the brine is conveyed to open trenches, shallow ponds, or pans, and evaporated by the heat of the sun. This method is also used in the manufacture of salt from brines obtained from salt wells, and is a common method of manufacture near Syracuse, New York. The following account of this method of obtaining salt from brine by the heat of the sun is taken from the report of F. E. Englehardt:[1]

The solar or coarse salt is made by the evaporation of brine in shallow wooden vats provided with movable wooden covers for protecting against rain. There are three sets of these vats or rooms, the first called the deep rooms, 12 to 14

1. New York State Museum, Bull. 11, p. 39.

inches deep, which receive the brine from the wells. In these vats the carbonic dioxide gas escapes and the iron is precipitated giving the brine a reddish color, but on complete precipitation of the iron, the liquid becomes clear.

The brine from the deep rooms is drawn into the lime rooms where evaporation continues until salt begins to crystallize; and if gypsum or lime sulphate is present, it begins to separate. The brine is now conducted to the third set of vats, the salt rooms, where the remaining gypsum crystallizes, and the salt crystals accumulate on the floor of the vat. The supply of concentrated brine from the lime or pickle vats is renewed from time to time, and when a sufficient quantity of salt has accumulated, it is raked to one side or harvested, drained, and removed to the store house. It may be sold unscreened as Standard Coarse, or it may be screened over coarse screen and sold in two grades at Syracuse under the names Diamond Coarse and Diamond Fine.

In a Syracuse salt yard, according to Englehardt, two-thirds of the vats are salt rooms which are 18 feet wide, with a length of 100 to 500 feet depending on the size of the plant, and 6 inches deep. The vats are built so that the floor of the first one is 6 or 8 inches higher than the second and so on for the different vats. The movable covers are in 16 foot sections which cover a space of 16x18 feet or 288 square feet.

In later years an improvement was introduced in the use of aprons in place of the deep and lime rooms. These aprons are shallow vats, 20 to 100 feet wide, 200 to 2,000 feet long, and about three inches deep. Upon these the brine in a layer one-half inch deep flows slowly down a grade of one inch in 100 feet, and is delivered saturated to the salt rooms. Storage tanks under the aprons are used and the brine run into these in case of rain. The large thin sheet of brine is rapidly concentrated by the sun's heat and air currents, giving greater capacity, to the plant. According to Chatard,[3] the capacity of a salt room or vat, 16x18 feet, has been increased from 50 bushels a season to 70 or 80 bushels by use of aprons, and in one case was increased to 92 bushels.

3. U. S. Geol. Survey, 7th Annual, p. 507.

According to Englehardt (p. 44), "the quality of the salt depends on the weather to a certain extent, but mainly on the intelligence and care of the workmen. Supplying the salt rooms with perfectly saturated pickle, allowing the harvested salt to drain properly both in the tub and the storehouse and finally to discharge the old pickle at the proper time, are of the utmost importance in the manufacture of a good commercial salt."

Mr. Englehardt states in his report of 1893, that there are at Syracuse, over 12,000,000 square feet of evaporating surface capable of producing 3,500,000 bushels of solar salt in a season which usually extends from the middle of March to the middle of November.

3. DIRECT FIRE EVAPORATION.

Kettle Method. Salt brines are evaporated by artificial heat applied to either kettles or pans containing the brine. In the first method,[4] a kettle block consists of 60 to 100 hemispherical cast iron kettles suspended in two parallel flues ending in a stack, 50 to 100 feet high. The kettles are 22 to 26 inches deep and 3 to 4 feet diameter with a capacity of 100 to 150 gallons. The flues are lined with fire brick and reach to within one foot of the bottom of the kettles, but farther back the bottom of the kettles is in direct contact with the flues and the hot gases of combustion. The brine is settled removing the iron and dirt impurities and then is conveyed in pipes to the kettles.

A shallow bittern pan is inserted in the kettles at first to collect the sulphate of lime which is removed and thrown to one side until evaporation has gone far enough for the crystallization of salt. The salt is removed from time to time into baskets and after drawing is taken to the store house. The front kettles are drawn every four to five hours while the back kettles may require 24 to 36 hours. In five to six days the kettles must be cleaned of sulphate of lime which forms a non-conducting incrustation on the bottom thereby increas-

4. **Englehardt,** ***loc. cit.*****, p. 49.**

ing fuel consumption. The time of operation of a kettle salt block is 10 to 15 days so that two runs are made a month. About 45 to 50 bushels of salt are made with a ton of slack coal at Syracuse.

Chatard[5] states that this is the original Syracuse method of evaporating brine and arose from the use of the potash kettle, the largest boiling apparatus known to the early salt makers who first used it in 1788. Later the kettle was set in an arch of stone, and in 1793, four kettles were combined forming a salt block. In 1860 the method was used at Saginaw, Michigan. It was also used in the Kanawha Valley of West Virginia and in some of the early Ohio plants, but it has now been practically abandoned in all these places.

Pan Method. In the pan method of evaporated salt, the brine is pumped from wells into large storage tanks and from these flows down into the pans which are made of wrought iron plates, about one-half inch thick, rivetted together. They are usually 20 to 25 feet wide, 80 to 100 feet long, and 12 inches deep, separated into two parts by a thin partition over which the brine slightly heated in the cooler portion of the pan, passes into the main portion where evaporation is completed.

The fire box or grate is five or six feet below the bottom of the pans, and is separated by a brick arch which is more or less broken to permit the heat to pass through and yet to protect the pan from the intense heat of the fire. Along the side of the pan is the sloping drip board to hold the salt. The temperature of the brine is kept at about 200° F., and when a sufficient quantity of salt has accumulated, it is raked to the drip boards where it drains. The hand rakes have long handles attached to a cross strip of steel 6 to 18 inches. The drained salt is removed to the store house and piled in compartments where it remains 30 to 60 days to dry, when it is packed in sacks, barrels, or loaded in cars in bulk.

The gypsum or sulphate of lime accumulates on the floor of the pans where it forms a hard scale, and being a non-conductor of heat soon lowers the temperature of the brine and

5. U. S. Geol. Survey, 7th Annual, p. 507.

decreases the output. It also tends to concentrate the heat on bottom of the iron pan which buckles and may even break. This hard scale is broken by crowbars and pried off in cakes which are removed to the waste piles. Outside of the West Virginia and Pomeroy Ohio salt brines, gypsum is in this way a most troublesome impurity.

Englehardt[6] states that the great advantage of the pan process over any other is in the control over grain of the salt. If a fine grained salt is desired, the fires are increased causing the brine to boil and the crystals forming rapidly are small in size. The addition of butter, especially prepared soft soap, or white glue forms a film over the surface of the brine and aids in making a very fine grained salt for table use. Such salt is removed once an hour, while coarser grades are removed in 2 to 12 hours according to the size of grain. Low fires and longer time permit the salt to form in larger crystals making the coarse grades. The temperature of the brine may thus vary from 212° to 145° F.

Englehardt found from his study of the New York practice that with coal slack and good weather, one ton of coal was sufficient for 80 to 90 bushels salt in summer season with saturated brine, but in winter would make only 68 bushels, with a yearly average of about 72 bushels.

4. STEAM EVAPORATION.

An attempt was made in New York to improve the kettle process by enclosing the iron kettle in steam jackets which increase the production from 45 or 50 bushels to 65 bushels to the ton of coal in the Warsaw district. The heat being uniform, the salt produced in the different kettles from front to back of the block was uniform in grain and quality.

Grainer Process. In the grainer or Michigan process, steam is driven through a set of pipes placed in the wood or iron vats, in transverse or longitudinal direction, thus furnishing heat for the evaporation of the brines. The process proved especially valuable in Michigan in conjunction with

6. *Loc. cit.*, p. 48.

the saw mills where the exhaust steam was available by day and live steam direct from the boilers by night, lowering materially the fuel cost. This method was also found valuable in working the weak brines of the Kanawha and Ohio Valley regions.

The vats or pans in the New York grainer plants [7] are 100 to 150 feet long, 12 feet wide, 20 to 24 inches deep, and contain 4 to 6 steam pipes with a diameter of 4 to 5 inches and suspended four to six inches above the bottom. The salt is removed by rakers every 24 hours, or automatic rakers move the salt constantly from front end of the grainer to the back where it passes up over an apron and falls into a conveyor which carries it to the salt bins.

The temperature is kept near the boiling point to secure the best results and brine is constantly supplied. The liquor remaining in the vats contains the bitter salts and becomes more and more concentrated. This bittern liquor still contains a considerable percentage of salt, so it is removed from time to time to another set of grainers where the balance of the salt is precipitated, usually coarse in grain and more or less impure, but is sold for cheaper uses. The brines before passing into the grainers are settled to remove iron and other impurities in the same manner as in the ordinary pan or kettle methods.

The lime sulphate or gypsum collects on the steam pipes forming a hard coat or scale. It is removed by increasing the steam pressure and heating the pipes which expand and crack the gypsum scale which is then readily removed. In the New York plants with grainer process, one ton of coal slack will produce 70 bushels of salt when saturated brines are used, and in Michigan 72 to 75 bushels. The Kanawha grainer system which differs in many respects from the New York and Michigan systems, will be described in the next chapter.

Chatard [8] states that the capacity of grainers is usually reckoned by the number of square feet of grainer surface re-

7. New York State Museum, Bull. 11, p. 59.
8. U. S. Geol. Survey, 7th Annual, p. 520.

quired to produce a barrel of salt in 24 hours, obtained by dividing the total number of square feet by the daily production in barrels. He states that the Saginaw, Michigan exhaust steam blocks average one barrel of salt to every 32 to 36 square feet of grainer and to every 2.5 horse power of boiler capacity. In the Kansas plants one barrel of salt is produced to 20 to 25 square feet of grainer.

5. VACUUM PAN EVAPORATION.

In the vacuum pan process, the brine is evaporated by steam with a reduced atmospheric pressure over the brine. The vacuum pan is a tall cylinder in which a reduced air pressure is maintained, lowering the boiling point of the brine, thus giving a more rapid evaporation and a finer grained salt.

Englehardt[9] states that in the New York vacuum pans, the steam is conducted through the cylinder in 17 or 18 groups of copper tubes 20 tubes in each group. The salt crystallizing falls to the bottom and is automatically removed and screened, while fresh brine is supplied above.

Bownocker[10] states that in the Wadsworth, Ohio plant there are two vacuum pans used, each of which is 40 feet high and 10 feet in diameter containing 800 evaporating tubes, 2½ inches diameter and 4 feet high. In the center of this group of tubes is a large one 24 inches diameter and 6 feet long, and the average temperature is 135° F. The vacuum is usually at 25 inches pressure maintained by an air pump and by the condensation of steam produced by the evaporation of the brine. One of the pans at the Rittman, Ohio plant has 1,004 tubes 4 feet long and 2½ inches diameter, with central tube 4 feet long and 2½ feet diameter.

IMPURITIES IN BRINE.

The following analyses by Dr. Goessman of New York brine and the pickle resulting from its concentration, are

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9. *Loc. cit.*, p. 61.
10. Ohio Geol. Survey, Bull. VI, p. 30.

quoted by Englehardt (p. 41). They show the loss of iron carbonate, decrease of lime sulphate, and proportional increase in percentage of salt, and the soluble lime and magnesium chlorides:

	Brine.		Pickle.	
Specific gravity	1.1225		1.2062	
Lime sulphate	0.5772	per cent.	0.4110	per cent
Lime chloride	0.1533	"	0.2487	"
Magnesium chloride	0.1444	"	0.2343	"
Potassium chloride	0.0119	"	0.0194	"
Magnesium bromide	0.0024	"	0.0039	"
Ferrous carbonate	0.0044	"	0.0000	"
Sodium chloride (salt)	15.5317	"	25.7339	"
Water	83.5747	"	73.3488	"

The lime sulphate is absent in the West Virginia brines on account of the presence of barium, but in most American brines, there is an absence of barium, and the presence of a considerable percentage of sulphate of lime which is a source of trouble as shown above in the different methods of evaporation of brines. It can readily be precipitated in the laboratory by a number of reagents,but such methods are found to be too expensive for use on a commercial scale.

The chloride of magnesia according to Chatard (p. 504) tends to make the salt fine grained, sharper in taste, and more rapidly soluble. Such salts containing this compound as made in the Kanawha and Ohio river regions are preferred for curing meats in warm climates.

The strength of brine is indicated by the specific gravity. A saturated brine at 60° F., has a specific gravity of 1.2055 and contains 26.47 per cent of common salt. The strength may also be indicated by the salometer which is a short glass tube so weighted that the point to which it sinks in pure water is marked 0 on the scale, and the point to which it sinks in a saturated brine at 60° F., is marked 100. The presence of lime and magnesia salts increase the readings, and a rise in temperature will lower the reading. Englehardt states that for all practical purposes it is sufficient to add or deduct one degree to or from the reading for every 10 degrees the temperature is above or below the normal.

BY-PRODUCTS FROM SALT BRINES.

In the Kanawha valley and Ohio river valley of West Virginia and Ohio near Pomeroy, the salt brines carry two important by-products, bromine and calcium chloride. The Michigan and Allegheny, Pennsylvania brines also carry bromine. On account of decline in price of bromine, the industry is not as valuable as some years ago.

Bromine Manufacture. According to the reports of Merrill in U. S. Geological Survey Mineral Resources, Pennsylvania was the pioneer state in the manufacture of bromine, where the industry started at Freeport in Armstrong county in 1846. The Ohio industry began at Pomeroy in 1868 and at Canal Dover Ohio in 1888, but was abandoned at the latter place. The bromine industry was started by Mr. Lerner at Mason City and above Charleston, West Virginia about 1872, and in Michigan in 1883.

The Midland, Michigan brines are said to contain four times as much bromine as those from other localities. According to Mr. Joseph Struthers,[11] thirteen companies were organized to produce bromine from the Midland brines since 1883, but in 1903 there were only two operating companies. He gives the following list of bromine producing companies in the United States in 1903:

Dow Chemical Company, Midland, Michigan.
Meyers Bros. Drug Company, Midland, Michigan (office St. Louis, Mo.)
Independent Chemical Co., Saginaw, Michigan.
Wayne Chemical Co., Saginaw, Michigan.
John A. Beck & Co., Allegheny, Pa.
Syracuse Coal & Salt Co., Syracuse,Ohio.
Coal Ridge Coal & Salt Co., Pomeroy, Ohio.
Buckeye Salt Co., Pomeroy, Ohio.
Excelsior Salt Co., Pomeroy, Ohio.
United Salt Co., Pomeroy, Ohio (no output since 1900).
Dickinson & Co., Malden, W. Va.
Hope Salt & Coal Co., Mason City, W. Va.
Liverpool Salt & Coal Co., Hartford, W. Va.
Hartford City Salt Co., Hartford, W. Va.

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11. Mineral Industry, vol. XI, p. 73; 1903.

The brines at the above localities except Midland have practically the same composition. On average 360 gallons of brine are required for one barrel of salt, and brine for 100 barrels of salt yields 55 pounds of bromine, though at Pittsburgh the yield has been as high as 75 to 80 pounds to 100 barrels of salt.

Except at the plant of the Dow Chemical Co., all use the same process. Sulphuric acid and potassium chlorate are added to the brine in stone stills of 400 to 800 gallons capacity, and the liquid agitated by steam jets under 40 pounds pressure. By the Dow process, the Michigan brine containing 0.1 to 0.2 of one per cent of bromine has this element freed from its alkaline bases by an electric current, and the free bromine is removed from the brine by a current of air blown through it, and absorbed from the air by caustic soda. In 1903, one-half the bromine production of United States, according to Struthers, was made by the Dow process at Midland.

According to Merrill,[12] the sulphuric acid produces from the bittern enough hydrochloric acid to act on the potassium chlorate liberating enough chlorine to free all the bromine. On application of heat, the bromine is liberated. The reactions are given by Merrill in the following formulae:

$$\mathrm{Na\,Cl + H_2\,SO_4 = Na\,H\,SO_4 + H\,Cl}$$
$$\mathrm{6\,HCl + K\,Cl\,O_3 = K\,Cl + 3\,Cl_2 + 3H_2O}$$
$$\mathrm{Mg\,Br_2 + 2Cl = Mg\,Cl_2 + 2Br.}$$

More or less chlorine is carried off with the bromine, often as much as 10 per cent, so the bromine is later redistilled.

The price of bromine in the past few years has ranged around 28 cents a pound. The following table of statistics compiled from the reports of the U. S. Geological Survey shows the total production of bromine in United States and in West Virginia, but since 1902, the statistics have not been given by states:

12. U. S. Geol. Survey, Min. Resources, 1905; p. 1097.

	Total Production Pounds.	W. Va. Pounds.	United States Value.	Price per lb.	Rank of W. Va.
1898	486,979	118,888	$126,614	28 cts.	third
1899	433,004	101,213	108,251	29 "	"
1900	521,444	114,270	140,790	27 "	second
1901	552,043	106,986	154,572	28 "	third
1902	513,893	93,375	128,472	25 "	fourth
1903	598,500	....	167,580	28 "	
1904	897,100	....	269,130	30 "	
1905	1,192,758	....	178,914	15 "	
1906	1,283,250	......	165,204	12.8 "	
1907	1,379,496	....	195,281	14.0 "	

The producing localities in 1906 were Midland, Mount Pleasant, St. Louis, Michigan; Pomeroy, Ohio; Allegheny City, Pennsylvania; Hartford, Mason, and Malden, West Virginia. According to the U. S. Survey, the decline in price is due to the imports of this material from Germany.

Bromine is used[13] in manufacture of bromides of potassium, sodium, and ammonia for medicine and photography. A small amount is used in the manufacture of the coal tar colors, Eosine and Hoffman's blue. It is used as a chemical reagent, as a disinfectant dissolved in water, also for bromo-cyanide process of gold extraction.

The manufacture of calcium chloride will be described under the description of the West Virginia salt plants.

13. Merrill, U. S. G. S. Mineral Resources, 1904, 1905.

CHAPTER XIV.

THE SALT INDUSTRY IN WEST VIRGINIA.

MALDEN IN KANAWHA VALLEY.

The numerous salt works which made the Kanawha valley famous 30 years ago have with one exception disappeared and only here and there remains an old stack or a pile of rubbish to mark their sites. The low price of salt and the discovery of richer brines in more northern districts have forced the companies, one after another, to discontinue operations. The one plant which is still in successful operation is located at Malden, six miles above Charleston on the Kanawha and Michigan railroad and on the north bank of the Kanawha river. It is located on the old Ruffner property and was built in the spring of 1865. It is owned and operated by Mr. Dickinson under the name of the J. R. Dickinson Salt Company.

The brine is pumped from a central plant by compressed air from three of the six wells, into a large wooden storage tank, 60 by 25 feet and 4 feet deep, holding 44,800 gallons. The wells are 800 to 900 feet deep with 6½ to 7 inch casing containing a 2 inch brine pipe and ½ inch compressed air pipe.

From the storage tank, the brine flows down a wooden pipe to the furnace heated by 15 gas jets and coal fuel is also added, using 60 to 75 tons a week, which is shipped from the company's own mines at Quincy seven miles up the Kanawha and Michigan railroad. The furnace walls are stone lined with fire brick and grate at one end. Above the furnace are the brine pans three in number which are about three feet deep, the first one 45 feet wide and 10 feet long; the other two, 30 feet wide and 8 feet long, in which the brine is concentrated

from a specific gravity of 1.048 to 1.063 with a salt percentage of 7.1 to 9.3 as received; to a gravity of 1.085 with salt percentage of 12.

Over these furnace pans is constructed a tight wooden box forming the steam chest, 30 inches high in the clear, which retains the steam which passes through wooden pipes under 4 pound pressure to the settlers and grainers. These pipes lead to a horizontal wooden log pipe line at the end of the vats and are connected by goose neck pipes with the five inch copper pipes running lengthwise of the vats.

The brine from the furnace pans is colored by the suspended iron oxide, mud, and sand, and is drawn off into the upper side of the first mud settler. The two mud settlers are long vats constructed of heavy planks, 165 feet long, 8 to 10 feet wide, 18 inches deep, and divided longitudinally through center by a plank partition. The brine entering the upper side flows to opposite end and there passes over a low place in the partition into the lower side and back to the head of the vat again. It there passes through a pipe into the second mud settler constructed on similar plan and the brine follows a similar course. By the time it reaches the head of the lower side of the second mud settler vat, it is perfectly clear and free of iron, mud, and sand. The brine is now ready for use and it has been kept at moderate temperature by the heat of the steam in the copper pipes running through the settlers, one pipe for each half of the settler.

The brine leaves the second mud settler with a gravity of about 1.125 or with a salt percentage of 17.2 and flows into one of the two settlers which are the same size as the mud settlers but divided by two longitudinal partitions into three compartments. The brine from the settlers passes into the fifth vat or the draw settler which is 165 feet long, 14 feet wide, 45 inches deep without partitions, and having the 5-inch copper steam pipes, and the brine is concentrated to a gravity of 1.170 to 1.179 or 22.5 to 23.6 per cent salt and salt crystals begin to form. It is then conveyed to the four grainers which are plank vats lined with clay tile plates, and are 150 feet long, 10 feet wide, 18 inches deep, and contain three

copper steam pipes the full length of the vats. In these the salt is deposited and removed by rakers to the salt cars and conveyed to the storage house.

After most of the salt is precipitated and the brine has a gravity of 30° Baume, the liquor is drawn into the tenth or bittern vat heated by two copper steam pipes, where it is further concentrated, and the rest of the salt precipitated. This salt is more or less impure and somewhat colored, and is sold for agricultural uses, or at this plant most of it is sold to the Kelley axe factory at Charleston where it is mixed with other materials to form a tempering mixture for steel. When this mother liquor has reached a gravity of 35° B., it is removed to the bittern water tank, to be subjected to further treatment for extraction of bromine and calcium chloride. The daily capacity of this plant is 125 to 150 barrels, and during 1907 produced between 45,000 and 50,000 barrels.

In this brine there is no gypsum or lime sulphate to contend with, the bromine in the brine would attack the iron pipes especially as more and more concentrated so the pipes are made by boring logs or in the vats, copper is used. The wood pipes have low radiation and heat conduction so there is low loss of heat with their use. The thin copper pipes permit the heat of the low pressure steam to be rapidly given up to the brine, and the vats are readily made on the ground and have a low expense of wear and tear. The mechanical conditions are all favorable to a low cost of manufacture, but the weak brine would increase the cost probably beyond any adequate profit beyond the investment, if the valuable by-products were absent or lost. It requires skillful and careful management to run such a plant with low gravity brine at a profit, but the company first organized in 1832 has been in successful operation ever since and to-day is looked upon as one of the prosperous industrial companies of this great valley so rich in natural resources. This salt is shipped by rail and water to distant points and is brought at many places into successful competition with Michigan and Ohio salt. Outside of its intrinsic value as one of the state's successful

industries, this is of historic interest as the only survivor of the 10 furnaces operating in this section 35 years ago.

Bromine Plant. The bittern water from the tank is carried to the bromine plant where it is heated in a furnace tank and concentrated to 41° to 43° Baume. This tank holds 250 to 300 gallons of bittern, and the concentrated liquor is drawn from it into stone stills where it is mixed with sulphuric acid, and potassium chlorate poured in from the top. About 25 pounds of acid and 8 pounds potassium chlorate are used to 400 gallons of bittern which yield about 25 pounds of bromine.

The still is made of two blocks of solid sandstone about five feet square and a total height of six feet, hollowed out at the center. Steam is blown into the mixture heating it to a temperature of 160° to 180° F., and making a thorough mixture. The bromine vapor passes down through two lead pipes through a condenser which is a rectangular wooden box, five feet long and one foot square in which cold water is constantly running around the pipes. The lower ends of the lead pipes empty into two bottles with connections sealed with clay to prevent escape of fumes. In the condenser the vapor is condensed to liquid bromine and as the bottles are filled they are replaced.

Plate IX shows the arrangement of a similar bromine plant in Ohio. The method is the same in all these plants in West Virginia and at Pomeroy Ohio. This plate has been kindly loaned by the Ohio Geological Survey through the courtesy of Prof. J. A. Bownocker, State Geologist.

Lime Chloride Plant. The residual liquor freed of bromine in the still is drawn from below into a cistern where it is treated with lime to neutralize the acid, and the liquor is pumped into the calcium kettles, two in number at this plant, but only one is in use. These kettles are enclosed in steam jackets and have a steam coil in the kettle furnishing the necessary heat. Each holds three tons of calcium, and the liquor is heated and condensed to a thick syrup which is then run into sheet iron drums holding 600 to 700 pounds. In a few hours the liquid cools and in a day or two forms a solid mass of calcium chloride which is ready for shipment. In

removing the material for use, the drums are cut or pounded off leaving the core of solid calcium. The daily capacity of the Malden plant in bromine is 22 bottles or 150 pounds, and 4 tons of calcium.

Geology of Kanawha Brines. No records have been preserved of these wells, but their depth to the salt sand is 800 to 900 feet. A record of a well drilled for gas, located on Cool Spring branch of Burning Springs Hollow, two or three miles from the Malden plant throws some light on the brine horizon. This record is given by Dr. I. C. White in volume I of the Survey reports (p. 272), and is here reprinted.

Dr. White in his explanation of this record states that the well started 100 feet below the Campbell's Creek coal, which would not be far from the horizon of the surface of these Malden salt wells. He states that the **salt sand** in this record is the brine horizon from which salt has been obtained through the Kanawha valley, and belongs in the Pottsville Series near the base of the Coal Measures of the Carboniferous with the Greenbrier Limestone of the Lower Carboniferous just below. This limestone is called by the drillers in southern portion of the state "the long running rock."

The record of this Edwards well No. 1, is as follows:

	Thickness. Feet.	Depth. Feet.	
Conductor	53	53	
Coal, trace	...	.....	
Sand, hard, white	100	153	
Slate, gray	8	161	
Sand, gray, strong smell of oil	40	201	
Slate, dark	25	226	
Sand, hard, white (*top of Salt Sand*)	174	400	
Coal, splint (?)	6	406	
Sand, hard, white, salty	200	606	
Slate, white	10	616	
Limestone, white (shale)	50	666	
Slate, white	40	706	837 feet.
Sand, hard, white	125	831	
Sand, hard, white, flinty, salt	130	961	
Slate, black	2	963	
Sand, hard, white	50	1,013	
Sand, hard, blue (*base of Salt Sand*)	50	1,063	
Limestone, blue, Greenbrier or "Long Running Rock", gas in bottom	300	1,363	
Red Rock, sandy, shaly	50	1,413	

Unrecorded	187	1,600
Sand, coarse, heavily charged with light oil	2	1,602
Slate, bl[illegible]	250	1,852
Slate, black	75	1,927
Slate, blue	323	2,250
Slate, shelly, with puffs of gas in last 50 feet	100	2,350
Slate, blue	50	2,400
Sand, shelly, with slight increase of gas	50	2,450
Slate, blue, very soft	92	2,542

Chemical Composition. The following analysis of the brine used at the Malden salt works was made in January 1905 by Mr. C. D. Howard of the West Virginia Agricultural Experiment Station:[1]

	Parts in 1,000 parts by weight.
Sodium chloride	60.1762
Sodium bromide	0.2238
Sodium iodide	0.00098
Sodium nitrate	0.00000
Sodium arsenite	0.0000097
Sodium borate	Small amt., not estimated
Potassium chloride	0.5700
Lithium chloride	0.1010
Ammonium chloride	0.0787
Barium chloride	0.7447—46.14 grains per gal.
Strontium chloride	0.2013
Calcium chloride	15.0103
Magnesium chloride	4.9692
Calcium bicarbonate	0.2661
Ferrous bicarbonate	0.0822
Manganous bicarbonate	0.0076
Calcium phosphate	0.0005
Aluminum	Trace
Silica	0.0040
	83.3456
Specific gravity at 15.5° C.,=	1.0628

A sample of the common fine salt from this plant shows the following composition as analyzed in the Survey laboratory:

1. Bull. 103, p. 284; 1906.

	No. 1 Salt.	Bittern Vat Salt.
Moisture	0.62	6.15
Silica and insoluble	0.015	0.017
Iron and alumina oxide	0.21	0.59
Lime chloride	0.69	4.35
Magnesium chloride	0.23	1.05
Barium chloride	0.02	7.70
Sodium chloride (common salt)	98.28	80.22
Potassium chloride	None	None

The salt from the bittern vat is sold for agricultural uses and represents the residue in the brine after the higher grades of salt are removed.

MASON CITY AND HARTFORD IN OHIO RIVER AREA.

The only other operating salt plants in West Virginia are located in Mason county at Mason City and Hartford, three miles apart, the former town being opposite the Pomeroy, Ohio salt plants. The two towns are located on the big bend of the Ohio river and on the Ohio River division of the Baltimore and Ohio railroad, 62 miles below Parkersburg. Of the 13 plants in operation in this area in the '70's, only three are now making salt.

Dixie Salt Co.

The only plant now in operation at Mason City is the Dixie Salt Co., formerly the Mason-Hope Salt Co., whose plant was built 35 years ago by the Hope Salt Co. This plant was shut down three or four years ago and was in very poor condition, but in the spring of 1907 was overhauled and partially rebuilt by a new company under the above name.

The wells are 1,250 feet deep with the brine found at 1,100 to 1,150 feet, and they are pumped by sucker rods from the depth of 600 to 800 feet, into the storage tank. The brine with a gravity of 8° B., or specific gravity 1.056 corresponding to 8.2 per cent salt, flows from the storage tank to the furnace. The furnace pans are in four sections, of which the first three contain 10 pans each, bolted together and 8 feet

long, three feet wide, while the fourth section is a single open pan 30 feet long and 8 feet wide. Over all these pans is the steam box made of plank similar to the Malden plant.

The heated brine is conveyed from the furnace pans through a wooden pipe to the first mud settler and then through the second and third, similar in construction and operation to the Malden plant, and from these passes into two draw settlers. The long vats are heated by the low pressure steam from the furnace steam box conveyed through wooden log pipes to four inch copper pipes in the vats. The brine is drawn from the draw settlers into five salt grainers, 80 feet long, 10 feet wide, and lined with clay tiles. The mother liquor is drawn into a sixth grainer forming the bittern vat, and from this with the bromine and lime chloride goes to the bittern tank.

By-Products. The bromine plant is similar in construction to the other plants and is housed in a small shed separated from the main plant. It contains one furnace and two stone stills. The liquor with the calcium chloride is taken across the river to the Pomeroy plant for further treatment. The daily capacity of this salt works is 200 barrels of salt, and 200 pounds of bromide.

Fuel. The fuel used is coal secured from the company's own mine back of the town, and brought down a long incline track to a coal storage shed above the level of the railroad. From this shed the lump coal is loaded in railroad cars for shipment, while the slack and poorer coal are used at the furnace. The coal mined is the Pittsburg seam,[2] 4 to 5 feet thick with the following composition according to the Survey analysis:

Fixed carbon	45.93	per cent.
Volatile matter	39.25	"
Moisture	1.87	"
Ash	12.95	"
	100.00	"
Sulphur	1.95	"
Phosphorus	0.013	"

2. Prof. J. A. Bownocker has recently claimed that this coal is the Redstone.

One bushel of coal is said to make one bushel of salt at this plant.

Geology. The wells were all drilled many years ago, and the works have changed ownership, so that if any records of the wells were ever preserved, they have been lost.

Across the river at Pomeroy, Professor Bownocker[3] gives the following record of a well drilled by the Buckeye Salt Co., where the top of the well is 25 feet below the Pittsburg or Pomeroy coal seam:

		Feet.
Conductor	...	58
Shale	58 —	550
White and gray sand	550 —	870
White sand and slate	870 —	960
Big Salt sand	960 —	1130
Sand and white shale	1130 —	1495
Berea grit	1545 —	1570
Total depth	....	1590

He states that brines were reported as follows:

Depth in feet.	Density.
320	6° B.
710	9° B.
980	9° B.
1550	16° B.

The brine in the Berea was much denser than that from the Big Salt Sand, but it was small in quantity.

Chemical Composition. Prof J. A. Bownocker in the report above quoted (p. 27) gives the following analysis of the Pomeroy brine from the Coal Ridge Salt Works:

3. Ohio Geol. Survey, Bull. 8, p. 25.

	Grains per liter of brine.	Grains per U. S. gals. of brine.
Silica	0.012	0.70
Iron and aluminum oxides	0.083	4.81
Calcium chloride	14.340	831.72
Magnesium chloride	5.590	324.22
Magnesium bromide	0.155	8.99
Strontium chloride	0.257	14.91
Barium chloride	0.343	19.89
Sodium chloride	84.300	4889.40
Sodium iodide	0.004	0.23
Sodium sulphate	0.000	0.00
Potassium chloride	0.114	6.61
Lithium	Trace	Trace
Specific gravity	1.075	

An analysis of the salt made from this brine is also given by Professor Bownocker:

Moisture	7.42
Sodium chloride	91.31
Sodium sulphate	0.00
Calcium chloride	0.95
Magnesium chloride	0.32
Silica, iron, alumina	0.00

Hartford City Salt Company.

Hartford City is located three miles above Mason City on the Ohio river. The plant of the Hartford City Salt Co., is located at the upper end of the town between the railroad and the river, and was formerly known as the Valley City Salt Co. The brine is pumped from five wells drilled to the Big Salt sand of the Pottsville Series, into the storage tanks located on the hills above the plant and flows from these by gravity into the furnace pans where it is heated. From these it passes with a gravity of 12° to 16° B., into two mud settlers, and then into two draw settlers, 145 feet long and 12 feet wide. From the draw settlers it is carried into six grainers, 126 feet long, 12 feet wide, equipped with automatic salt rakers which push the salt forward at a rate of 4½ feet a minute, discharging it on a conveyor belt which carries the salt to the storage house.

By-Products. The residual brine from the last grainer is drawn into the bittern vat and concentrated to 36° B., yielding a small quantity of agricultural salt. The bittern

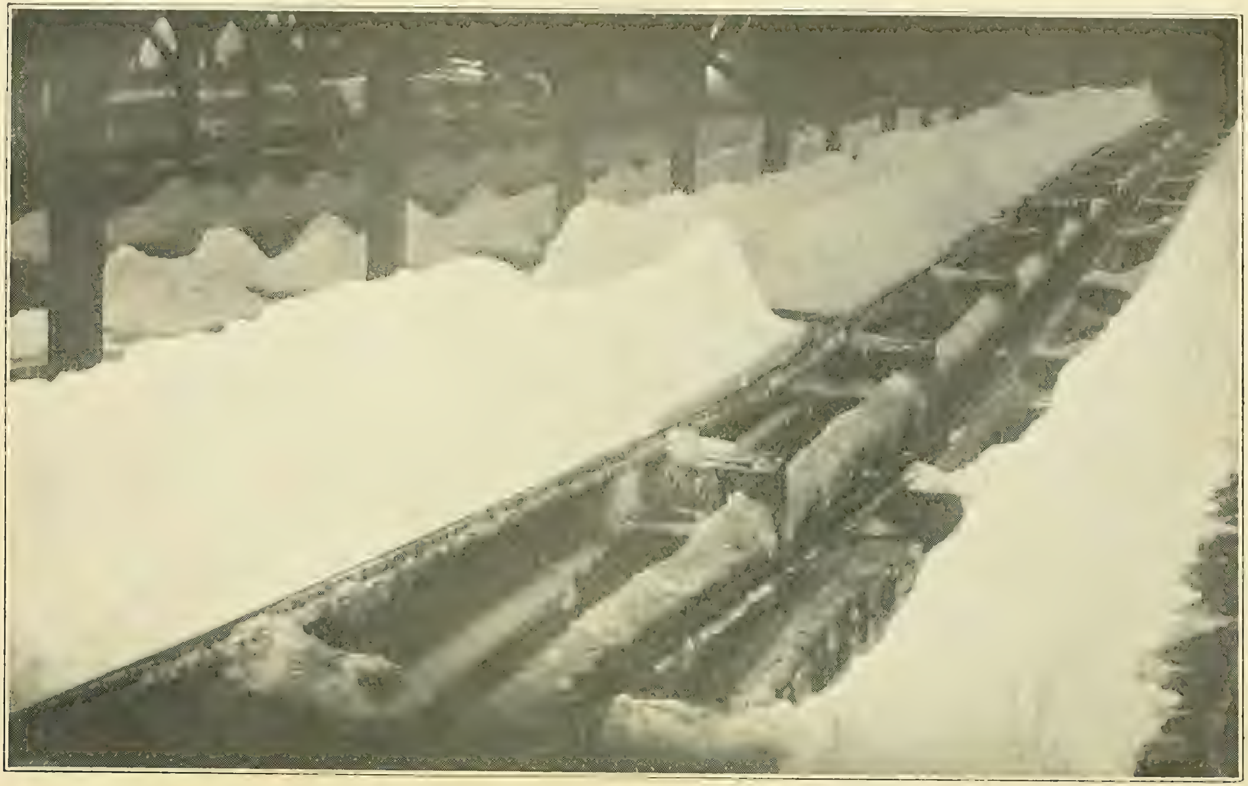

Plate XI.—Interior View of Plant of Liverpool Salt and Coal Company at Hartford City, Mason County.

is then heated in the bromine pan, and the bromine extracted in two stone stills which are 7 feet high with a 5-foot opening on the interior and made of Buena Vista sandstone. The liquor after removal of the bromide is run into a tank where the acid is neutralized by lime and has a gravity of 47° to 50° B. It is then boiled in the three calcium kettles heated by steam, until the calcium forms a thick syrup which is run into the sheet iron cans where it hardens in one to three days.

The daily capacity of the plant is 250 barrels of salt, 125 pounds of bromine or an average of ½ pound to the barrel of salt, and 5 to 6 tons of calcium or about 10 pounds to the bushel of salt.

Fuel. The Pittsburg coal, 4½ to 5 feet thick, mined in the hill back of the plant is used for fuel. The composition of this coal is shown by the following analyses, one furnished by the company, and the other made by the Survey for the coal report (volume II):

	Company.	Survey.
Fixed carbon	51	49.91
Volatile matter	39	39.79
Moisture	2	2.80
Ash	8	7.50
	100	100.00
Sulphur	1	2.02
Phosphorus	..	0.017

Chemical Composition. Mr. C. D. Howard[4] gives the following analysis of the Hartford City brine taken in March 1904, but does not state from which one of the two plants the sample was taken:

	Parts in 1,000 parts by weight.
Sodium chloride	74.191
Potassium chloride	0.415
Lithium chloride	0.0093
Ammonium chloride	0.130
Barium chloride	0.341=21.33 grains per gallon.
Calcium and strontium chloride	12.554
Magnesium chloride	5.438
Calcium bicarbonate	0.171
Iron oxide and alumina	0.048
	93.2973
Specific gravity at 15.5° C.	1.0732

4. W. Va. Univ. Agr. Exper. Station, Bull. 103, p. 285.

Mr. Howard states that a special search for the elements, calcium and rubidium, in this example resulted negatively.

Liverpool Salt and Coal Company.

The plant of the Liverpool Salt Co., is located at the lower edge of the town of Hartford and to the south of the railroad track. A view of this plant is shown in plate X, and plate XI gives an interior view of the grainers and salt.

The process of manufacture of salt from brine at this plant is similar to that at Malden described above. Tubular boilers 72 inches in diameter and 18 feet long are used for production of high pressure steam for use in the evaporation of the brine in the grainers.

The wells are 1,100 to 1,200 feet deep with 600 feet of brine in them. The daily capacity of the plant is 350 to 400 barrels of salt, 175 to 200 pounds of bromine 1¼ to 2 tons of calcium. The Pittsburg coal is used as fuel.

Geology. The wells secure their brine from the Salt Sand of the Pottsville Series. The following record of one of the more recent wells, furnished by Mr. H. F. Smith, the general manager, shows the character of the formations, the top of the well being about level with the Pittsburg coal:

	Feet.	
Drift	300	
Horseneck sand	50	
Shales	110	
First Cow Run sand	40	
Shales	250	
Second Cow Run sand	40	
Shales	210	
First Salt sand	50	
Shales	55	
Second Salt sand	60	(used for brine)
Total depth	1,165	

The following record is of a well drilled on the Sehon farm at Hartford, for T. W. Fleming. The correctness of the log is attested by a sworn affidavit of the driller, C. P. Wil-

liams, and was furnished by Wm. C. Meyer of Morgantown. It shows the order of the rocks 667 feet below the Pittsburg coal at Hartford:

Bottom of Pittsburg coal	28	feet.
Red rock and shale	272	"
White sandstone	35	"
White shale	42	"
Black shale	12	"
White sandstone	20	"
Brown and white sand shale	50	"
White sand	51	"
Slate	20	"
White sand	40	"
Brown and white shale	35	"
Slate	6	"
Slate and coal, Upper Freeport	5	"
White shale	8	"
White sand rock	28	"
Black slate on top Freeport coal	8	"
Coal clean	7	"
Total	667	"

Chemical Composition. The salt from the first grainer and also from the third grainer at the Liverpool Salt & Coal Company plant, were analyzed by the Survey with following results:

	1st grainer.	3rd grainer.
Moisture	2.24	3.04
Silica and insoluble	0.01	0.01
Iron and alumina oxides	0.15	0.33
Lime chloride	1.54	4.30
Magnesium chloride	0.43	1.06
Barium chloride	0.05	0.90
Sodium chloride (common salt)	95.32	90.20
Potassium chloride	None	None

CHAPTER XV.

THE USES OF SALT, CALCIUM CHLORIDE, AND STATISTICS.

USES OF SALT.

Salt has been regarded as one of the necessities of life from the earliest times, and in the most ancient records, its occurrence and use have been mentioned. Herodotus speaks of the early use and occurrence of salt in Persia and Asia Minor. It was even an important offering in places of worship among the ancient Hebrews, Greeks, and Romans, and reference to its religious uses are given in the books of the Old Testament. Its use sealed the bonds of friendship among a primitive people. It is even stated that the oldest trade highways were created for the salt traffic. Extensive salt mines were worked in northern India before the time of Alexander, and among certain people, salt was even used as money. The early writings of the Jesuit missionaries to America from 1645 to 1700 mention the salt springs of New York state and regarded them as valuable treasures of the trackless wilderness of that far away time.

The uses of salt at the present time may be grouped as follows:

Domestic.—Table, cooking, preserving, pickling, dairy, ice cream.

Industrial.—In refrigerating cars, meat packing, thawing of

Industrial.—In refrigerating cars, meat packing, thawing of
ice, salting hides, fertilizer, timber preservation.

Chemical.—Manufacture of soda ash, salt cake, caustic soda, chlorine, carborundum.

Mining.—Chlorination of gold ores.

Domestic Uses. Table salt is made by rapid crystallization with higher temperature in the pans than ordinary salt, thereby making a finer grained product. It is in some plants dried in revolving hot air dryers and precaution is taken to make it as pure as possible and free from the bitter chlorides. Ordinary cooking salt is usually coarser in grain, though on account of low price of salt, table salt is also used in cooking. Salt is used for preserving meats, salting pork, preserving eggs, butter, etc. A brine is made for pickling vegetables and meats, and for these purposes a cheaper grade can be used. In the manufacture of ice cream almost any grade can be used, and the smaller sizes of the rock salt are used, in many places. In 1906, according to the U. S. Geological Survey, Michigan, New York, and Ohio were the largest producers of table and dairy salt, the total quantity being about one-tenth the total quantity of salt produced, and value was about one-sixth.

Industrial Uses. Salt, especially rock salt, is used with ice in packing refrigerator cars. According to Kirk[1] in the Kansas salt report, about 500 to 600 pounds are used to a car. It is also used in packing barrels of meat for export, a layer being placed on top and bottom. The West Virginia salt has been held in high favor for packing and especially for preserving meats in warm climates, as the absence of lime sulphate keeps the salt from forming a hard cake, and it remains loose, and so readily penetrates the meat. The barium in this salt has also been looked upon as having an antiseptic value, but the experiments of C. D. Howard of the West Virginia Experiment Station appeared to show that barium chloride had no pronounced antiseptic qualities. Salt is used for removal of ice on pavements, street car rails and other places, and is used in salting hides. Any of the grades can be used, but the coarser and cheaper grades are bought for such uses.

Salt has for many years been regarded as a valuable fertilizer, though there is considerable difference of opinion as to its real value. Professor Kedzie of the Michigan agricultural Experiment Station speaks of salt as a useful and

1. Univ. Geol. Survey, Kansas, Mineral Resources 1898, p. 102.

cheap manure which judicially applied, frequently yields a large increase of corn, roots, or hay, and seldom does any harm. He states that salt has a remarkable tendency to prolong the period of vegetation and delay the arrival of maturity.

Prof. Kedzie explains the value of salt on land in the following words as quoted in a pamphlet issued by the Michigan Salt Association:

"It will be seen that the value of a fertilizing agent does not always depend upon the fact that it is an essential element of nutrition. * * * * It may as in the case of chloride of sodium, not even make its appearance in our grain crops, and yet it may be instrumental in materially raising the produce of wheat.

"Again, such non-essential salts in general, may nevertheless play an important part in the nutrition of plants by assisting the solution and uniform distribution of fertilizing constituents which occur in the soil in a sparingly soluble or insoluble condition. It is well known to chemists that chloride of sodium exercises a dissolving action upon solid bodies; and thus it is not too great a stretch of fancy to assume that it will act beneficially in the field by dissolving and rendering available earthy fertilizing constituents which without its aid will remain in an inert condition for a long time."

Salt is also said to be of great value in the orchard by promoting the growth of the tree and destroying the larvae of insects, and it has been used with good results on grass land. Its use seems to attract very favorable attention in Michigan and New York.

Storer[2] states that it is an open question whether salt will destroy fungi and insects when used in small quantity as commonly applied to land. With heavy dressing of salt he believes there would be danger of destroying the useful micro-organisms which act to keep land sweet and mellow and preventing the acid character.

Salt, according to Storer acts on the soil indirectly in effecting the decomposition of substances already present in

2. Agriculture, vol. II, p. 599.

the soil, and sets free from them some things which are needed by plants. Common salt displaces lime first, then magnesia, potash and some phosphoric acid to a less extent. Salt is sometimes used to prevent grain stalks from becoming too rank on rich soils. On heavy land salt flocculates the soil, that is, causes the mud or clay particles to cohere, thus making it more plastic and permeable to water (Storer). Care must always be taken not to use too much salt on the land as it tends to unite with water forming a concentrated solution which if in sufficient quantity might injure the seeds or minute rootlets. It may be used in fields for killing troublesome sprouts.

Chemical Uses.

Soda Ash and Salt Cake Manufacture. Salt is used for the manufacture of soda ash or sodium carbonate in the LeBlanc and Solvay processes. The LeBlanc process consists of two stages.[3] In the first stage, common salt is converted into sulphate of sodium by the action of sulphuric acid producing the acid sulphate of soda according to the

$$\underset{\text{(salt)}}{2\ Na\,Cl} + \underset{\text{(sulphuric acid)}}{H_2\,SO_4} = \underset{\text{(hydrochloric acid)}}{H\,Cl} + \underset{\text{(acid sodium sulphate)}}{Na\,HSO_4} + Na\,Cl$$

formula, but at a higher temperature the acid sulphate decomposes the remainder of the salt, forming a normal sulphate of sodium or salt cake.

$$Na\ SO_4 + NaCl = Na_2\ SO_4 + H\ Cl$$

In the second stage, the sulphate is mixed with limestone and coal or charcoal and calcined in a reducing flame forming a mixture of lime sulphide (Ca S) and carbonate of soda, the oxygen passing off as carbonic dioxide shown by the following formula,

$$Na_2\ SO_4 + 2C + Ca\ CO_3 = Na_2\ CO_3 + Ca\ S + 2\ CO_2$$

3. Encyc. Brittan., vol. XXII, p. 242.

The sulphide of lime is practically insoluble in water so the sodium carbonate is extracted by leaching with water at moderate temperature (below 160° F.)

The hydrochloric acid is one of the important by-products of the first stage, and is one of the main sources of the commercial acid. It was formerly allowed to go to waste, but at present time most of it is recovered.

Solvay Ammonia Process. In the Solvay process for the manufacture of sodium carbonate from sodium chloride (comon salt), limestone is used to generate the carbonic dioxide gas. The carbonic dioxide is passed into a concentrated solution of sodium chloride which has previously been saturated with ammonia. The reaction is brought about in a tower in which the brine flows down while the carbonic dioxide is forced up, and the temperature is kept down to 35° C. The reaction is as follows:

$$\underset{\text{(salt)}}{Na\ Cl}+\underset{\text{(ammonia)}}{NH_3}+H_2O+CO_2=\underset{\text{(sodium bicarb)}}{Na\ H\ CO_3}+NH_4\ Cl$$

The sodium bicarbonate is not as soluble as the rest of the constituents, and can be separated on filters. When heated, carbonic dioxide (CO_2) is given off and the bicarbonate changed into the carbonate thus,

$$2Na\ H\ CO_3=Na_2\ CO_3+CO_2+H2\ O$$

The liquor containing ammonia chloride ($N\ H_4\ Cl$) is treated with the lime obtained in burning for carbonic dioxide. This liberates the ammonia as a gas which is returned for further work in the process. This reaction would be

$$2\ (NH_4\ Cl)+CaO=2NH_3+Ca\ Cl_2+H_2\ O$$

The waste liquor from this process contains mostly calcium chloride with some sodium chloride, and from this liquor the pure calcium chloride can be obtained by crystallization. The supply from the Solvay plants is usually in excess of the demand, so that much of it is wasted.

In the Hargreaves process[4] of making sodium sulphate, sulphurous acid obtained by ignition of pyrites, is used with air and steam. It was patented in 1870 and the reaction is as follows:

$$2NaCl+SO_2+H_2O+O=Na_2SO_4+2HCl$$

The salt is rendered porous by first moistening with water, then redrying by passing it through a hot air channel on an endless chain of plates.

The salt is then distributed through not less than eight cast iron cylinders through which pass successively a current of mixed super-heated steam, and sulphurous acid given off by the pyrites. The reaction begins at about 400° C., and increases in energy with rise of temperature, but if heated beyond 500° to 550° C., the charge begins to fuse and is no longer permeable by gases.

The sodium sulphate or salt cake is used in large quantity in the manufacture of window and bottle glass. In manufacture of window glass the following mixture is sometimes used,

	Pounds.
Sand	100
Salt cake	36
Limestone	65
Arsenic	5
Carbon	4

In the manufacture of plate glass, sodium carbonate or soda ash is used. French plate is made with following mixture:

Sand	100
Soda ash	34
Limestone	15

4. Encyc. Brittanica, vol. XXII, p. 243.

The sodium carbonate is the basis for manufacture of a variety of chemical compounds. Soda crystals (or washing soda) are made from a strong solution of soda ash (carbonate sodium) allowing it to settle, then running it into large coolers or crystallizing vessels in which the crystals form in seven to ten days. The crystals are then broken up, drained and dried. They contain about 63 per cent water with formula $Na_2\ C\ O_3$, 10 $H_2\ O$, and are used for laundry purposes.

Caustic soda is made from the carbonate by adding lime hydroxide (milk of lime) with reaction,

$$Na_2\ CO + Ca\ (HO)_2 = Ca\ C\ O_3 + 2\ Na\ H\ O$$

Chlorine which is an important bleaching and oxidizing agent and may be made from the chloride of sodium, potassium, and magnesium. In the LeBlanc process of making sodium sulphate the hydrochloric acid formed as a by-product is treated with manganese, setting free the chlorine.

Chlorine is also made from common salt by passing through its solution a current of electricity which sets free chlorine and forms caustic soda.

Carborundum is an artificial silicon carbide first made by E. G. Acheson in 1891, and now made on a large scale at Niagara Falls. It is used as an abrasive replacing emery and corundum. The charge consists of,

	Parts.
Sand	100
Coke, crushed	100
Common salt	25
Sawdust	

These materials thoroughly mixed are fused in an electric furnace which is an oblong brick box, 16 feet long, 5 feet wide and 5 feet deep, with the electric terminal carbon rods in the center of the end walls. In the center is the coke core, 21 inches diameter and 14 feet long, made of small pieces of coke, and over it is piled the above mixture to a

height of 8 feet. A 185 volt current is turned on through the carbon terminals connecting with the coke core and continued for 36 hours. A single furnace yields 7,000 pounds of crystalline carborundum, and the plant is equipped with 15 furnaces, using the electric power from Niagara Falls power plant. The material is then crushed and sorted into 20 grades according to size. It is used for hones, carborundum wheels, paper, etc., for various abrasive purposes.

The sawdust is used to keep the mixture porous for the escape of gases, the salt causes adhesion between the particles of the charge and aids in the combination of the silica of the sand and the carbon of the coke. The reaction is given by Thorpe as:

$$Si\ O_2+3C=Si\ C+2\ C\ O$$

Carborundum is the hardest substance known except the diamond, it is almost infusible, and is insoluble in acids.

Chlorination of Gold Ores.[1] Chlorine readily unites with gold forming gold choride, and the metal can thus be separated from pyrite concentrates. The chlorine is made in leaden vessels by the action of sulphuric acid upon manganese dioxide and common salt. The gas is purified of any hydrochloric acid present by passing it through wash bottles containing water. The chloride of lime is commonly used in place of the common salt.

The roasted gold concentrate is placed in a water-proof vat with a perforated false bottom above the floor of the vat, and the chlorine admitted betwen the two floors, after the charge has been moistened with water. The gas permeates the ore and unites with the gold forming gold chloride $Au\ Cl_3$. After 12 to 24 hours the action is complete, and water is run in from above and the gold chloride is removed in solution to the precipitating vat. With thorough treatment by the chlorine and thorough washing by water, it is stated that 90 to 95 per cent of the gold is removed from the concentrate.

5. Huntington and McMillan, Metals, p. 470.

In the precipitating vat, a solution of ferrous sulphate is introduced in sufficient quantity to precipitate all the gold with the following reaction, according to Thorpe,

$$2\ Au\ Cl_3 + 6\ Fe\ SO_4 = Au_2 + 2\ Fe\ Cl_3 + 2\ Fe_2\ (SO_4)_6$$

Uses of Calcium Chloride.

One of the common questions in connection with the manufacture of lime or calcium chloride is, what are its uses? The West Virginia and Pomeroy Ohio salt plants produce a considerable quantity of this compound as a by-product, and it represents one of the important sources of profit in the salt industry of these districts. The Carbondale Chemical Co., of Carbondale, Pa., general sales agents of the Solvay Process Co., of Syracuse, N. Y., have kindly placed at the disposal of the writer, 30 small bulletins on calcium chloride which form the basis of the following discussion. The solid calcium chloride sold by the company contains 75 per cent of anhydrous chloride of calcium, the remainder being water of crystallization with less than ½ of one per cent of harmful impurities. The more prominent uses of this material will now be described.

Fire Protection. According to statements of the two Mutual Insurance companies quoted in these bulletins, more fires are extinguished annually with pails of water than by all other fire extinguishing apparatus combined, and one pail of brine is worth four pails of water for this purpose. The salt water corrodes metallic buckets, but a solution of chloride of calcium with its low freezing point, does not freeze. It does not become foul, has no effect on iron or steel, and being a strong absorbent of moisture, the buckets always remain full. It is especially valuable in an automatic sprinkler system.

Calcium chloride is used in 20 per cent solution in water jackets of automobile gasoline engines where it will withstand a temperature of 9 degrees below zero Fahr., without freezing, while its boiling point at 220 F., meets all requirements.

Refrigerator Machine Use. Chloride of calcium is claimed to have an advantage over salt brine for refrigerator plants, because it will withstand lower temperature, and has no action upon iron or brass, thus increasing the life of the brine tanks, expansion coils, and brine circulating pumps. Its cost is somewhat greater but 25 per cent less of the calcium than salt is required. It is used in ice factories, cold storage warehouses, packing houses, oil refineries, dynamite factories, chemical works, etc., where ice making machinery is used.

Manufacture of Dry Colors. Calcium chloride is used at lower cost in place of barium chloride in the manufacture of certain dry colors as, Eosin Lake, Turkey Red, Maroon, Bremen Blue. It is substituted for an equal equivalent of barium chloride, the two having the same value. The saving in cost on 100 pounds of Eosin Lake is 12 cents. A Turkey Red mixture is as follows:

Soda ash	75	pounds.
Alum sulphate	150	"
Barium chloride	210	"
Barytes	200	"
Scarlet	30	"
Orange	30	"
Total	695	"

The 210 pounds of barium chloride may be replaced by 150 pounds of calcium chloride, with a saving in cost of 17 cents per 100 pounds of the color compound.

Tempering Solution. When steel or iron are immersed in pure water, the formation of steam on the surface of the hot metal prevents the water from acting quickly on the metal; the use of salt or sodium chloride, and calcium chloride, the use of either of which materially raises the boiling-point as well as the specific gravity of the tempering bath, prevents the rapid formation of steam, because retarding the evaporation of the water and allows the cold brine to produce the proper hardening effect. A concentrated solution of calcium chloride is 100 per cent stronger than a concentrated solution of salt, and does not corrode the steel.

Canning Vegetables. The Winters continuous calcium process involves the use of an open top iron tank 4½ feet wide, 4 feet deep, and of a length determined by one foot length to every 1,000 cans to be used per hour, with top level with the floor. This tank contains a solution of chloride of calcium of such density or specific gravity that it will not boil at the temperature of canning, 240° to 250° F. This bath is heated by a steam coil, at first with live steam, and then maintained with exhaust steam.

The cans are placed in revolving iron crates or baskets hung from an overhead trolley system which moves so as to carry the crates from one end of the bath to the other, the cans remaining submerged long enough to complete the operation of cooking. Upon leaving the bath, the crates are conveyed by similar device into the cold water bath for rinsing and cooling; the cans are then ready for labeling and boxing. The calcium chloride solution will not boil even if steam pressure varies, and the temperature is uniform and easily regulated. The system is replacing the high pressure steam kettles and vats which are liable to explosions and save in labor. It is stated that a foreman with four unskilled helpers can prepare 8,000 cans per hour with this system.

Increasing Strength of Lime. Mr. Thomas W. Cappon found that a magnesium lime has its binding or cementing power greatly improved by the use of small quantities of calcium chloride. This use is claimed to be especially desirable in making wall plaster without use of gypsum, resulting in a very high grade hard plaster by use of sand, magnesian lime, and calcium chloride.

It has also been found effective in retarding the set of Portland cement. The experiments in the Sibley Laboratory indicated that chloride of calcium added in small percentages either to the ground clinker as a powder, or mixed with the water in guaging, has an important effect in extending the time of setting of Portland cement, and apparently it has no harmful effect on the permanent strength and hardness. Its use in dry form with the clinker is as yet doubtful on account of the calcium absorbing water.

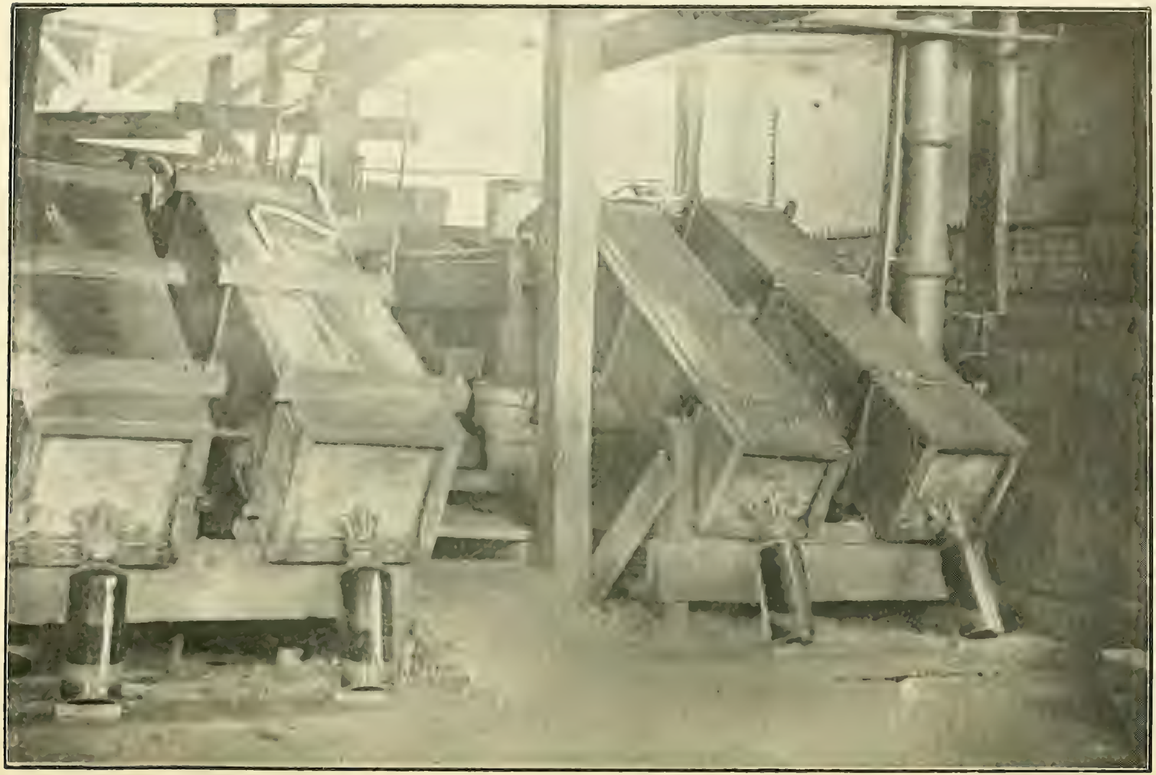

Plate XII.—Bromine Plant Used in the Ohio Valley Salt Works.
(By courtesy of Ohio Geological Survey.)

For Dessication. Calcium chloride with its strong affinity for water becomes an important drying agent. It is used for drying chemical products, aniline colors, pottery, vegetables, fruits etc. It allows rapid removal, with precision, and at low temperatures, the water contained in the bodies to be dried. This water when removed from these products, can be driven from the calcium chloride, by introducing it with asbestos, pumice, or coke, into an oven heated to several hundred degrees.

Thawing Ground. In excavations for sewers, water pipes, foundations, etc., it is claimed the ground can be thoroughly softened by drilling holes three or four inches deep, about one foot apart, and pouring hot calcium chloride in the form of a 30 per cent solution into these holes. This permeates the ground and removes the frost, no matter how deep, and prevents further freezing, because the freezing point of the 30 per cent solution is 32 degrees below zero F.

The use of calcium chloride with Portland cement on a basis of two or three per cent of the cement used, retards the setting of the cement mortar and prevents its freezing. It permits the chemical action necessary to the proper hardening of the cement to proceed gradually and completely, and causes no efflorescence. It can be used to keep ice from railroad frogs, and switches and does not dissolve as soon as common salt.

Dust Prevention on Highways. A road sprinkled with calcium chloride will for a long time remain damp and therefore dustless, because having a strong affinity for moisture, calcium chloride absorbs during the hours of the evening and night whatever moisture it may have lost during the day.

For the first treatment, a length of 100 yards of road, 8 yards wide, or 800 square yards, will require about 800 gallons of solution about 20 per cent made with three pounds of chloride to the gallon of water. Later applications would be made with 300 gallons of the solution, and about four applications during the sprinkling season would usually be sufficient.

The calcium chloride is shipped in 600 to 700 pound cast

iron drums, also in granular form in wooden barrels. The 40 per cent solution is shipped in 4,500 gallon tank cars, also in 110 gallon iron drums which after use are returned to the company.

Calcium chloride is used for preserving railroad ties, fence posts and other timbers at reduced cost over chloride of zinc which costs $60 per ton compared with calcium chloride at $10 a ton.

STATISTICS.

The production of salt in the Kanawha valley in 1814, and from 1827 to the close of 1875 have been given in the historical chapter.

The production and value of salt in West Virginia and the total salt production of the United States are given in the following table compiled from the reports of the United States Geological Survey from 1883 to the close of the year 1907:

SALT PRODUCTION WEST VIRGINIA AND UNITED STATES 1883-1907.

(U. S. Geological Survey.)

West Virginia				United States.
Year.	Rank.	Barrels	Value.	Barrels
1883	4	320,000	$211,000	6,192,231
1884	4	210,000	195,000	6,514,937
1885	5	223,184	145,070	7,038,653
1886	5	250,000	162,500	7,707,081
1887	6	225,000	135,000	8,003,962
1888	5	220,000	143,000	8,055,881
1889	6	200,000	130,000	8,005,565
1890	7	229,938	134,688	8,776,991
1891	..	*	*	9,987,945
1892	..	*	*	11,698,890
1893	7	210,736	68,222	11,816,772
1894	8	194,532	51,947	12,967,417
1895	7	176,720	63,041	13,669,649
1896	8	176,921	50,717	13,850,726
1897	7	441,893	160,129	15,973,202
1898	7	247,668	88,462	17,612,634
1899	8	221,534	107,987	19,708,614
1900	7	243,873	118,407	20,869,342
1901	7	231,722	94,732	20,566,661
1902	8	208,592	97,721	23,849,231
1903	8	244,236	35,797	18,968,089
1904	7	575,000	66,470	22,030,002
1905	8	202,151	74,063	25,966,122
1906	9	200.055	57,584	28,172,380
1907	9	156,147	76,527	29,704.128

* Not given.

The following table from the U. S. Geological Survey shows the production of salt in West Virginia in 1907 by grades:

	Barrels.	Value.
Table and dairy salt..............	48,000	$27,232
Common fine salt..................	108,147	49,295
Common coarse salt..............		
Other varieties and brine.........		
Total	156,147	$76,527

This table shows a change in the distribution of grades of salt in 1906:

	Barrels.	Value.
Table and dairy salt	5,000	$ 3,000
Common fine salt	106,037	47,428
Common coarse salt	9,018	3,156
Other varieties and brine	80,000	4,000
Total	200,055	$57,584

WORLD'S PRODUCTION OF SALT IN 1906.
(U. S. Geological Survey.)

	Short tons.	Value.
United States	3,944,133	$ 6,658,350
United Kingdom	2,201,293	2,900,983
France	1,496,923	4,198,329
German Empire	2,059,096	5,000,823
Japan (1904)	773,776	4,852,049
Italy	586,424	1,119,786
Austria	414,465	9,717,164
Russia (1903)	1,828,646	3,652,074
Spain	597,422	782,407
India	1,296,674	1,916,092
Canada	72,697	342,315
Tunis	69,004	45,548
Total	15,540,553	$ 41,185,910

PART III.

The Sandstones of West Virginia.

CHAPTER XVI.

THE CLASSIFICATION, STRUCTURE AND ORIGIN OF THE SEDIMENTARY ROCKS.

Architecture, or the art of building in accordance with the rules of utility, stability, and beauty, had its origin in the early days of civilization.

Primitive people sought shelter in caves, which formed natural rock houses, or they erected artificial structures out of the material at hand. Where timber was abundant, huts were constructed, while on the open plains or treeless deserts a tent of skins sufficed; but where rocks were abundant, these were rolled into sheltering *cairns*. The houses of worship, the graves of the dead in order to be more enduring were made of stone.

Whether the first structures of primal architecture were timber huts, skin tents, or rock cairns depended on the available materials of the native country, and the three forms of construction were without doubt nearly contemporaneous in the history of the ancient world.

Thus early structures like the dolmens of England, the

pyramids of Egypt, etc., built of stone endure to this day as relics of ancient people, while their huts and tents are mingled with the dust of ages. From the dawn then of civilization, stone has been the popular building material for enduring structures.

At a later date the temple and cathedral architecture from the days of Solomon's great temple, have been wrought in stone. In more recent years the brown stone fronts have typified wealth.

The selection of a stone for building depends on enduring quality, color, ease of working, availability, and cost, the last principle often unfortunately being predominant to the loss of the others.

ROCK CLASSIFICATION.

The rocks of the earth are classified in three groups—igneous, sedimentary, and metamorphic. Under *igneous rocks* are included all which have been formed through the agency of great heat. They are represented by the massive crystalline and semi-crystalline rocks of the oldest geological period, the Archaean, and known as granites, syenites, diorites, etc.; also by the crypto-crystalline volcanic rocks, as rhyolite, obsidian, etc. This group of rocks is not known in the state of West Virginia, except in very limited areas though found in the states to the north, east, and south.

The *sedimentary rocks* are those which were deposited under water as sediments, later consolidated by pressure and cementation into solid rocks raised into land areas. They are formed from the waste of older rocks and are therefore secondary in origin. The first sedimentary rocks were formed from the waste of the igneous rocks which composed the original surface or crust of the earth. The later sedimentary rocks were formed from the waste of igneous rocks and also from existing sedimentary rocks. The sediments are thus worked over into new rocks many times and their history is most complicated. Examples of this group of rocks are, shale, limestone, sandstone etc.

When these rocks, igneous and sedimentary, are altered by great heat and pressure due to molten rock flows, or to mountain making forces, they are changed in structure usually becoming harder and crystalline, and these types are known as *metamorphic rocks.*

To illustrate such changes, clay or mud compacted and consolidated into rock forms shale often called locally, soapstone, a type of sedimentary rock. When this shale is further hardened by great heat and pressure it becomes a slate, a metamorphic rock. Limestone in the same way becomes marble, bituminous coal is changed to anthracite, and may even pass over into graphite. Sandstone becomes a hard quartz rock known as quartzite.

This group of metamorphic rocks is poorly developed in this state, there being no roofing slate, no true marble, no typical quartzite. The mountain making forces were active in the eastern part of the state and the rocks in places are found to be hardened and partially changed so that hard slates, hard and compact limestones, and hard sandstones almost quartzite are found and are popularly termed slates, marble, etc.

The important group of rocks in West Virginia is therefore the sedimentary. They contain a variety of minerals characteristic of this group of rocks and some characteristic of the igneous rocks, which at some former time in their history furnished the sedimentary material.

MINERALS IN THE SEDIMENTARY ROCKS.

A rock is a mass of inorganic matter composed of one or more minerals. It is usually without definite chemical composition.

The mineral composed of one or more chemical elements has a definite chemical composition, definite physical properties, and often occurs in well marked crystals. Only a few minerals are characteristic of the sedimentary rocks, though a variety of accessory ones may be present. The more important types are described in this section.

Quartz. The mineral quartz while found in many igneous rocks is characteristic of the sedimentary rocks being found in clay, shale, and composing 50 to 99 per cent of sandstone. It may occur in prismatic crystals which are elongated, tapering and six sided. The mineral is brittle breaking usually with uneven fracture or a shelly (conchoidal) surface, and cleavage is indistinct or absent.

Its hardness in the old Moh's scale (1 talc. to 10 diamond) is 7 or harder than steel so that it cannot be scratched by a knife blade. It is the only common glassy mineral that will cut or scratch glass. Its specific gravity is 2.6 to 2.65.[1] The mineral when pure is colorless, but with impurities may have a variety of colors, as rose quartz, smoky quartz, amethyst (quartz colored pink to purple probably by manganese). It is transparent in pure crystals and opaque in massive form or when impure.

Chemically, quartz is composed of one part silicon to two parts oxygen, a compound designated as silica. When theoretically pure it contains 46.7 per cent silicon and 53.3 per cent oxygen. It is almost insoluble so that it remains unaltered for long periods of time when exposed to the weather and is therefore a very durable mineral. It is only soluble in hydro-fluoric acid.

Quartz is an essential component of such igneous rocks as granite, porphyry, rhyolite, and often occurs as a vein stone filling crevices of greater or less width and then may be associated with valuable ores.

It composes the greater part of sand, flint gravel, sandstone, pebble conglomerates. In these rocks it is dull in luster usually opaque, milky white to glassy color, though by impurities a variety of colors may occur. It may be identified by its hardness, lack of cleavage and therefore absence of light reflecting surfaces. If the mineral has been long subjected to action of water the pebbles or grains will be rounded, otherwise they will be angular. Flint, chert, hornstone are synonyms for quartz.

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1. That is a given bulk of quartz will weigh 2.6 to 2.65 times as much as an equal bulk of distilled water.

Mica. This mineral has a very perfect basal cleavage causing it to break in thin plates which are tough and more or less elastic. On account of their low electrical conductivity, these plates when of sufficient size are of value in electrical work. In the rocks the mineral occurs as very small plates or more often scales which are readily identified by the perfect cleavage, bright surfaces, and softness as they are very easily scratched by a knife blade. The hardness is only 2.2 to 2.5 while the specific gravity is 2.7 to 3.

There are two varieties of mica found in the rocks: muscovite and biotite. The former is colorless to a light brown and sometimes gray or yellow. The flakes are transparent to translucent. When a yellow color they are often mistaken for gold by people who have given no special study to minerals. Muscovite is the more common mica in the rocks being present in clay and shale and often abundant in the sandstones. It is found in many igneous rocks and is one of the essential components of granite.

In the sedimentary rocks it has come originally from the igneous rocks and is a very durable mineral, only very slowly acted on by weathering agencies.

Chemically muscovite is a potash aluminum silicate with the following somewhat complex formula $H_2\ K\ Al_6\ (Si\ O_4)_3$. In its theoretical form it would contain,

	Per cent.
Silica	45.2
Alumina	38.5
Potassium	11.8
Water	4.5
	100.0

Biotite mica differs from muscovite in containing iron, so its color is dark green to black. It is a little harder and somewhat higher specific gravity.

Feldspar. The feldspar group includes a number of varieties made up essentially of the chemical elements, potassium, sodium, lime, aluminum, silicon, and oxygen. The

potassium feldspar is known as orthoclase while the soda-lime feldspars are called plagioclase. While both feldspars are found as accessory minerals in sedimentary rocks, orthoclase is the more common, and it is also an essential mineral in granite and other acid crystalline rocks.

Orthoclase Feldspar has a vitreous luster and varies in color from colorless to yellow, brown and red. It has a very perfect cleavage so that the mineral reflects the light and appears brilliant in the rock mass thus differing from quartz which forms a dull mineral in the rock. Its hardness is 6 or about that of a steel knife and its specific gravity is 2.57. Chemically it is a silicate of alumina and potash with the following formula K_2O, Al_2O_3, $6SiO_2$. This formula would call for the following theoretical composition:

	Per cent.
Silica	64.7
Alumina	18.4
Potassium	16.9

Feldspar is found in many sandstones, also in shale and clay, and like mica had its original source in the crystalline rocks. Through weathering action it changes into the mineral kaolin which forms the base of clay.

Kaolin. This mineral which is secondary in origin being formed by the decomposition of feldspar or other silicate mineral has the following formula and chemical composition when pure: $2H_2O$, Al_2O_3, $2SiO_2$.

Silica (SiO_2)	46.5
Alumina (Al_2O_3)	39.5
Water (H_2O)	14.0
	100.0

If this formula is compared with the one given above for orthoclase, it will be seen that the alteration involves the loss, wholly or in part, of potash and the substitution of water, also the loss of four parts silica.

Kaolin is a soft mineral with a hardness of 2 to 2.5 and specific gravity of 2.6. The mineral occurs massive rather than in crystals. It shows cleavage and the plates so formed are flexible and inelastic, rhomboidal or hexagonal in shape. The mineral is smooth or soapy to the touch, has a strong affinity for water and when pure is white in color, but it is found in a great variety of colors due to impurities.

Kaolin is present in many sandstones and sometimes forms the cementing material of the rock and then makes a very poor building stone. When the feldspar of the granite changes to kaolin it greatly weakens the rock and may cause it to crumble.

Pyrite or iron sulphide has the chemical formula FeS_2 containing when pure—sulphur, 53.4 per cent; iron, 46.6. It breaks with a conchoidal or shelly fracture, or with an uneven surface and is quite brittle. Its hardness is 6 to 6.5 and specific gravity 4.95 to 5.1. The cleavage is indistinct and luster, metallic. The color is pale brass yellow and opaque. Pyrite is found in igneous, sedimentary and metamorphic rocks, and has a wide distribution. On account of the color it is often mistaken by people not familiar with minerals for gold.

Iron Ores. In addition to the sulphide of iron, other iron minerals are sometimes found in building stone. These are the three oxides: Magnetite, Fe_3O_4; hematite, Fe_2O_3; and limonite, $Fe_2O_3+H_2O$. These minerals are described in detail in this volume in the part devoted to iron ores. When present in building stone they are liable to be partially leached and thereby stain the stone.

Calcite, or lime carbonate, is represented by the chemical formula $CaCO_3$ and when pure contains lime oxide 56 per cent, carbonic dioxide (CO_2) 44 per cent. In its pure form it is white or colorless, but usually contains a variety of impurities, magnesia, iron, manganese, etc., which give various shades of color. The lime carbonate occurs often in crystals, rhombic, tabular or long prismatic in shape with perfect cleavage. Its hardness is 3 and specific gravity 2.7. These crystals are found in crevices, cavities, etc., of igneous

and sedimentary rocks. When found in veins through limestone rock, they are sometimes mistaken for quartz. It is readily distinguished from quartz by its softness as it is easily scratched by a knife, also by its effervescence when hydrochloric or other acid is applied.

In the massive form lime carbonate forms limestone, marl, etc. Limestone consists of lime carbonate, sometimes crystalline and often without crystal form.

Dolomite is composed of lime and magnesium carbonates and when pure contains,

	Per cent.			Per cent.
Lime oxide	47.9	or	Lime carbonate	54.35
Carbon dioxide	21.7			
Magnesium oxide	30.4	or	Magnesium carbonate	46.65

It forms rhombic crystals with perfect cleavage. Its hardness is a little greater than calcite 3.5 to 4 and its specific gravity 2.8 to 2.9. Dolomite crystals are difficult to distinguish from calcite; the difference in hardness is small but dolomite effervesces very slowly, if at all, in cold acid while calcite shows strong effervescence. The dolomite dissolves readily with effervescence in hot hydrochloric acid.

In origin dolomite has been formed by the partial replacement of lime carbonate by magnesium carbonate. Dolomite forms massive strata like limestone and is then usually found in regions of mountain uplift. If the limestone contains less than 25 or 30 per cent. of magnesium carbonate and over 8 or 10 per cent. it is called a magnesian limestone. Limestones with over 30 per cent of magnesium carbonate are usually called dolomites.

Lime Sulphate occurs in hydrous form, gypsum; and without water, anhydrite. Gypsum is represented by the chemical formula $CaSO_4+2H_2O$, and when pure would contain 79.1 lime sulphate 20.9 per cent water. Its hardness is 2 and can be scratched by the finger nail, its specific gravity is 2.3, a cubic foot weighing 140 pounds. When crystallized it occurs in transparent plates and prisms cleaving into parallel leaves like mica except the plates lack elasticity.

Gypsum occurs also in solid rock ledges and in earthy form. When heated to 370° F. it loses part of the water forming plaster of Paris which will set on the addition of water. The formula becomes $(CaSO_4)_2, H_2O$, calling for 93.8 per cent lime sulphate and 6.2 per cent water. Plaster of Paris sets in a few minutes, so a retarder is added in the form of an organic preparation to delay the set for a number of hours, and the product is sold under the name of cement plaster which has become a formidable rival to the lime industry.

Anhydrite has the composition of gypsum without the water, its chemical formula being $CaSO_4$. Its hardness is greater, 3 to 3.5, and its specific gravity is 2.8 to 2.09. When pure, anhydrite contains 41.2 per cent of lime, 58.8 sulphur trioxide, and when calcined it does not set on addition of water. It is formed from gypsum by the elimination of the water, a reaction greatly aided by pressure, and in the deep well samples, in Michigan anhydrite is found instead of gypsum.

Lime Silicate or Wollastonite has the chemical formula $CaSiO_2$ which would give the composition as 48.3 per cent lime, 51.7 per cent. silica. Its hardness is 4.5 specific gravity 2.8. It occurs in tabular crystals or short prisms in granular limestones especially near granite contacts .

Lime Phosphate or apatite is widely distributed in minute crystals in granites and occurs in large deposits in Spain, Norway, and Canada, associated with limestones. It is mined and used in manufacture of phosphate fertilizers.

Lime Fluoride, or fluorspar occurs usually in the form of cubes often of marked beauty. When pure it contains 51 per cent. of lime and 49 per cent. of fluorine. Fluorspar occurs in veins associated with limestone and granites. It is mined in Kentucky, Illinois, Tennessee, and Arizona, for use as a flux.

Fourteen other minerals with lime as the base combined with arsenic, antimony, titanium, chlorine, etc., are given by Dana in his System of Mineralogy.

Lime is also found in a number of silicate minerals which are important rock forming constituents; 10 per cent in horn-

blende, among the feldspars 5 per cent in plagioclase, 12 per cent. in labradorite, 20 per cent. in anorthite, 18 per cent. in the scapolites, also in pyroxene, sphene, zeolites, epidote, and some garnets. Lime is found in varying percentages in the sedimentary rocks, shales and sandstones.

IGNEOUS AND METAMORPHIC BUILDING STONES.

While no igneous or metamorphic building stones are found in the state of West Virginia such material is often used in the state being brought from other sections of the country so that the types are familiar. A brief description of these rocks is included for the information of those interested.

Granite is one of the oldest rocks in the geological series, as well as forming eruptive masses in more recent formations. It is composed essentially of the minerals, quartz, feldspar and mica with a variety of accessory minerals. The rock is crystalline and granular, the color determined by color of constituent minerals. In its best forms it is one of the most durable rocks and lends itself to architectural decorative work as it can be carved into any form and will take a high polish.

According to Professor G. P. Merrill[2] granite has a weight of 166½ pounds to the cubic foot, or about 2 tons per cubic yard, and its crushing strength is between 15,000 and 20,000 pounds per square inch.

Gneiss has similar chemical and mineral composition to granite, but differs from it in having the minerals arranged in more or less parallel layers giving the rock a striated or banded appearance. The rock has a tendency to split along these planes in working.

Most of the granites used in this country come from the eastern part of the United States, Colorado, Missouri, Minnesota, California, and it is also imported especially from Scotland. The prominent eastern states for granite are, Maine, New Hampshire, Connecticut, Massachusetts, Maryland, Virginia, Georgia, North Carolina.

2. Stones for Building and Decoration, p. 176.

Serpentine[3] popularly called green stone is a hydrous silicate of magnesia, consisting when pure of nearly equal proportions of silica and magnesia with from 12 to 13 per cent of water. The massive varieties quarried for architectural purposes are always more or less impure, containing frequently from 10 to 12 per cent of iron oxides, together with varying quantities of chrome iron, iron pyrites, hornblende, olivine, etc. Serpentine is a secondary product due to the alteration, usually of eruptive rocks rich in magnesian minerals.

The serpentine rocks while greenish in color are usually streaked with various shades of brown and black, giving a mottled rock. It is soft and can be carved or turned on lathe so is popular for interior work, and it has been used for exterior walls. Quarries have been worked in Mass. Conn. N. Y. Maryland, Penn.

Marble. A crystalline limestone that will take a polish is often called marble, but in geology marble is a crystalline carbonate of lime formed from limestone by the action of great heat and pressure as present in mountain making. It is therefore a metamorphic rock.

Important quarries are found in Vermont, Conn. Mass. N. Y. N. J. Pa., Tenn. Md. Va. Ga., N. Carolina. Vermont produces nearly two-thirds of the marble of the United States.

Onyx Marble[4] has similar composition to marble but is a chemical deposit instead of altered limestone. It has been formed by the evaporation of water holding lime carbonate in solution. Its banded character and variegated colors are due to the intermittent character of deposition and the kind and quantity of mineral impurities. Real onyx is a variety of agate or banded quartz and therefore a silicate rock. The onyx marble is so called from its resemblance in bands to the true onyx.

Professor Merrill states that owing to their translucency, delicacy and variety of colors, the readiness with which they

3. Merrill, *loc. cit.* p. 53.
4. Merrill, *loc. cit.* p. 116.

can be worked and the high polish they admit of, these onyx marbles have long been favorites for smaller ornamentation and highly decorative work, and will doubtless long so continue.

The popular onyx in this country comes from Mexico, also from San Luis Obispo California. Of the foreign deposits, those in Algeria and Egypt in northern Africa are the most famous.

The stalagmitic deposits in caves have been worked from time to time as onyx in Virginia, Missouri, and other places. The rock in these cases is apt to be soft in texture dull in color, and often coarse and friable, so that they have not proved popular.

Slate. Ordinary clay, consolidated into rock forms shale, and shale metamorphosed by heat and pressure becomes slate with a more or less crystalline structure. The slates have a well developed fissile character which causes them to break readily along parallel lines leaving smooth surfaces. This structure appears to have been developed by great pressure at right angles to the planes of division. Not all of the material develops this structure as some of the most resistant layers remain unaltered or only partially changed, and others are crumpled and fissured so greatly as to be worthless. All such material represents waste in the slate quarries. According to Davies as quoted by Professor Merrill,[5] in the Welsh slate quarries 16 to 20 tons of waste to one of merchantable material is a frequent occurrence, and good paying quarries have been worked where 100 tons of rock must be removed to obtain 3½ tons of good slate.

Slate is used for roofing purposes, billiard tables, mantles, floor tiles, school slates. Merrill states that for the last use a soft even-grained stone is required, and nearly the entire supply is brought from Penn. and Vermont.

While valuable slates are found in many eastern states the more important districts are in Maine, Maryland, New York, Penn. Vermont, Virginia.

The Martinsburg shales are found in a series of folds

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5. *Loc. cit.* p. 297.

in Berkeley county near Martinsburg, West Virginia, and breaks into plates showing a fissile character. The shales are brown to black in color, micaceous, with cleavage, often well developed. A few years ago they were exploited and a number of slate companies chartered resulting in considerable excitement but with little development. While the slate might be used for interior work, it would make poor roofing material.

Dr. T. Nelson Dale of the U. S. Geological Survey made a careful study of these so-called slates and his results are given in Chapter XVIII.

CLASSIFICATION OF THE SEDIMENTARY ROCKS.

The sedimentary rocks may be classified into three groups depending upon the chemical nature of the rocks.

Argillaceous Rocks. This group includes the clay rocks whose base is kaolin, or aluminum silicate. It includes two important rocks which differ from each other only in the amount of consolidation.

Clay may be defined as an earthy mass composed of kaolin and various mineral and organic impurities. It is one of the most common rock types being found with wide geographical and geological distribution. In warm dry climates blocks of clay, sun dried, under the name of adobe are used as building material for walls and the dried clay slabs also for roof. The value of clay as a building material is in its use for an artificial block or in form of brick. Clay therefore with possible exception of the adobe could not be classified as a form of building stone.

Shale is indurated or hardened clay. It usually breaks in parallel layers and weathers to clay. In its chemical composition and physical properties, shale is the same as clay. When wet, shale like clay has a smooth slippery feel somewhat like a bar of soap so is popularly called soapstone. True soapstone is talc a secondary mineral formed from magnesian silicates of igneous rocks, and used for fire proof material.

Calcareous Rocks. In this group are included the rocks made up of lime.

Limestone consists of lime carbonate, sometimes crystalline and often without crystal form, associated with various foreign impurities so that the percentage of lime carbonate is variable, ranging in the limestones of this State from 98.2 to 52.7 per cent., the impurities being magnesium carbonate, silica, iron, alumina, phosphorus, titanium, alkalies, and organic material. The different varieties of limestone are given below.

Massive limestone which occurs. in strata of varying thickness and composition, is the rock ordinarily used for lime, cement, ballast, flux, etc. A fine, even-grained limestone suitable for stone engraving is known as lithographic stone, and is found in several places in this country, but the greater supply is imported from Solenhofen in Bavaria.

Hydraulic limestone has a considerable percentage of silica and alumina (10 to 30 per cent.) in addition to the lime carbonate. When burned it forms a cement which will set under water.

Chalk is a soft incoherent limestone formed mainly from shells of microscopic animals of the group Foraminifera. Large deposits are found in England and across Europe, in a belt nearly 1,000 miles long, also in central and western parts of the United States.

Oolite is limestone with granular texture composed of more or less rounded masses like fish eggs which give it the name oolite or egg-stone. The best known deposit in this country is the Bedford, Indiana, stone which is extensively used as a building and trimming stone.

Marl is a soft, earthy lime carbonate, and represents a lime sediment unconsolidated. It is found in lakes, swamps or stream valleys in many parts of the country from a few inches to 40 or 50 feet in thickness.

Marls are often described as impure lime carbonate deposits associated with high percentage of clay, but the Michigan marls, used in Portland cement manufacture are of high degree of purity with very small percentages of clay and other impurities.

Travertine is formed by the evaporation of water from

springs containing lime carbonate in solution. In Yellowstone Park, according to Weed, it has been deposited to a large extent through the work of fresh water plants known as Algae.

Onyx marble is a variety of travertine often with a banded structure due to the intermittent deposition, and capable of taking a high polish. It is found in a number of western states and is used for ornamental work in place of marble.

Stalactites and stalagmites are formed in caves, the former projecting from the roof and the latter from the floor, forming columns and pinnacles. The lime carbonate is deposited by evaporation of the water dripping from the roof. They possess a concentric structure and often reach large size.

Dolomite is a lime-magnesium carbonate rock where the lime carbonate has been partially replaced by the magnesium carbonate. In the pure crystal form it consists of 54.3 per cent. of lime carbonate and 45.7 per cent. magnesium carbonate. Dolomite forms massive strata like limestone and is then usually found in regions of mountain uplift.

Marble is crystalline limestone which will take a high polish formed from ordinary limestone or dolomite by the forces of heat and pressure associated with metamorphism.

Siliceous Rocks. The silica rocks are usually hard rocks though their durability must be determined by a variety of factors.

Sand. The loose unconsolidated silica material in form of sand is a valuable building material but not to be classed as a building stone.

Gravel would differ from sand in the size of the grains being composed of pebbles of larger and smaller size.

Sandstone is sand compacted into rock, the sand grains being held together by the pressure which was applied making a solid mass, or more often by the cement formed by precipitates from solution in water. The character of this cement is very important in the determination of the strength of the rock..

Conglomerate is the compacted pebble rock and may be coarse or fine according to the nature of the gravel from which it was formed.

STRUCTURES IN SEDIMENTARY ROCKS.

Stratification. Sedimentary rocks are separated into beds or layers by parallel planes, a structure which has been called stratification. Sedimentary rocks are therefore stratified rocks. A series of beds of the same mineralogical composition is called a stratum and the subdivisions of the stratum are called beds or layers. As an illustration there might be a stratum of limestone underlaid by a stratum of sandstone and covered by a stratum of shale, the three strata separated into beds by planes of division. According to Le Conte probably nine-tenths of the surface of the land and the entire sea floor are covered with stratified rock.

The lines of division between the. strata are due to change in character of material deposited in the old seas where the rocks were formed. In a quiet, comparatively shallow sea where corals and shell animals flourished, the lime sediments accumulated, but with an elevation of adjacent land areas increasing the flow of rivers thereby bringing in a load of mud sediment, the corals, etc., would be driven out and over the lime would be deposited the mud forming shales. By change in currents sand might be brought in and a sandstone formed. The study of the nature and origin of the sedimentary rocks gives clues to the physical conditions of the former seas. Wherever sedimentary or stratified rocks are now found, the area was covered at one time in geological history by the sea. From the calculation given above from Le Conte, at least 9-10 of the present land area was at a former time under the waters of the sea.

The beds of a given stratum may have their division planes formed by a change in character of deposited material, the coarse becoming fine or vice versa. The division planes may be due to the segregation of some one mineral as mica so that the stratum breaks along these planes. An interrup-

Plate XIII.—Batson Quarry in Dunkard Sandstone at Hundred, Wetzel County.

tion in deposition even in similar sediments may result in division planes due to hardening or cementation, forming beds or finer laminae.

Position of the Stratified Rocks. All undisturbed stratified or sedimentary rocks are horizontal or nearly so in position. They would preserve the various inequalities present at the time of their deposition. The sea floor is not entirely level, but is usually inclined from the shore line toward the open ocean, and the sediments deposited on this floor would have a similar inclination. The sedimentary rocks now forming land areas where there has been no folding or marked disturbance of the strata are not level or horizontal but incline slightly. The rocks of Ohio and western part of this state are inclined at a low angle to the southeast. The strata will vary in thickness and often thin out when followed in certain directions, just as the sand on the ocean coast today may be thick towards the coast line gradually thinning as followed further out to sea. The group of limestones in the northern part of West Virginia thin out as followed southward, many of them entirely disappearing. In a similar way the sandstones thicken when followed in the same direction.

In mountain areas, the sedimentary rocks are folded, tilted, broken, and overturned. All of these changes are found in the mountain area of the eastern part of this state.

Folds. The amount of folding in rocks may vary from microscopic size to those whose width and height are measured in miles. They are the result of lateral pressure at right angles to the direction of the fold. The upward fold, which inclines opposite directions from the central line or axis of the fold is called an anticline. The downward fold which dips from both sides toward the axis is called a syncline.

Erosion may remove the tops of these folds leaving rocks inclined in the opposite directions of the anticline, or together as in the syncline. If these folds are restored in diagram by prolongation of the inclined rocks, the form of the fold may be seen, sometimes rising high in the air. The

limestone strata near Martinsburg represent this feature, erosion has here removed the tops of the folds and there remain, as it were, the roots of an old mountain range now leveled to a plain by the forces of air and water.

Cross or Current Bedding. In some sedimentary rocks the laminae of one bed may be inclined with reference to the others parallel to the planes of stratification. Such a structure is called cross bedding and is seen more commonly in sandstones. It may be caused in sands or other sediment by the wash of waves or currents piling up the materials in form of minature hills, later effaced by overlying sediments in horizontal layers when the wave or current action is absent.

Ripple marks, wave marks, rain drop prints, sun cracks, may be preserved in the sediments and then in the consolidated rocks. All these structures as well as that of cross-bedding give evidence of shallow water or mud flat conditions, so may be used to locate the position of old shore lines.

Dip and Strike. The inclination of strata to a horizontal plane is called the dip. It is usually expressed in degrees and direction, as S 10° E. The angle varies from 0° to 90° or from horizontal to vertical.

The line at right angles to the dip is called the strike or according to Le Conte it is the direction of the trend of the rocks, or the line of intersection of the strata with a horizontal plane.

Outcrop and Unconformity. Outcrop represents the exposure of the rock to light of day, and is usually very irregular due to erosion. Unconformity refers to interruption in sedimentation where two contiguous formations have been formed under different conditions separated by a gap in the record marked by erosion.

A land area has its rocks eroded leaving an irregular surface and is later depressed below the sea. New sediments are laid down on the old eroded land area, and later consolidated into rock raised into dry land. The new sedimentary rock would be unconformable on the old rocks. The strata of the two series may be parallel or not, depending on

whether the older rocks were tilted or not before the addition of later sediments.

Faults are slips or displacements in the rock in which one portion of the stratum is thrown past the other part. The amount of displacement varies from almost nothing to thousands of feet. In portions of the Appalachian Mountains the vertical displacement reaches 20,000 feet.

Veins according to Le Conte are accumulations mostly in fissures or fractures in the earth's crust, of certain mineral matters usually in a purer and more sparry form than they exist in the rocks. The veins vary in width from hair like streaks to several feet wide. Cavities may be formed by contraction of the rocks on cooling or by later solution, and these may be filled with vein material. Limestone is often seamed by calcite or crystallized lime veins.

Cleavage is a property in rocks which causes them to break into thin laminae leaves. It is typical in slates and so is called slaty cleavage. The lines pass across the planes of bedding and are probably due to pressure at right angles to the cleavage planes.

Fossils are the impression or remains of animals and plants buried in the rocks by natural causes. Where the form and structure of the animal or plant are preserved by the replacement of the organic material by mineral matter, the forms are called petrifactions. In other cases the structure is lost and only the form preserved as in fossil shells so common in many sedimentary rocks. In other cases the animal body disappears leaving a cavity which may be filled with clay, sand or other material with the form of the original animal. Such fossil imprints are called casts. Many of these are found in the Oriskany sandstone capping the mountain ridges in the eastern part of this state.

ORIGIN OF THE SEDIMENTARY ROCKS.

Shale. The clay and mud deposited on the old sea floor probably accumulated very slowly as the clay rocks are made up of thin laminae caused by changes in accumulation. The clay was then consolidated by pressure or cementation

or both into more solid rock known as shale. Shale rocks stand for a muddy sea in past history of the earth, and the conditions must have persisted for long periods of time in some places from the evidence of thick shale deposits. The Martinsburg shales are 2,000 feet in thickness. In order to reach this thickness the shallow sea was subsiding forming a great sediment filled trough.

Sandstone. Along the coast line today gravels and sands are accumulating formed by the wash of boulders and the breaking up of land rocks the debris being carried into the ocean. Near the shore would be the coarser gravels then coarse sand grading into finer and finer sand toward the open sea. This fragmental material cemented together by lime, iron, silica, or clay binder would form rocks, the pebbles consolidated into conglomerate the sands into sandstone, and the finer sands into grits. Mingled with the sand would be various impurities, shells, fragments of wood, and various chemical compounds precipitated from the water, so that the sandstone formed would be composed of sand plus various, mineral, organic, and chemical impurities.

The value of the sandstone as a building material will depend on the composition and especially on the nature of the bond which holds the particles together. The color will be due to the kind of material and so will vary in different sandstones and may even change by exposure in the same rock.

Limestones are of chemical and organic origin. Some writers have regarded the massive limestones, especially of the earlier geological periods, as of purely chemical origin, but the generally accepted theory is that most limestones are of organic origin.

The preceding paragraphs show that lime occurs in a variety of mineral forms and rock types, and that the total quantity of lime in the earth is very large. Lime carbonate is soluble in water, and the chemical analyses of spring, river, and lake show a marked percentage of this compound. As the rivers flow to the ocean, they carry the lime in solution into these basins, and the enormous quantity of lime in the oceans has been stated above.

CHAPTER XVII.

HISTORY OF THE GLASS SAND INDUSTRY IN WEST VIRGINIA.

Glass, chemically, is a fused mixture of alkaline silicates, alkaline earths, and metals; or in other words it is usually a sodium lime silicate. According to Linton[1], glass may be classed under seven heads as follows:

1. *Polished Plate.*—Embracing all glass cast upon a smooth plate, rolled with a roller, annealed, and then ground and polished.

2. *Rough Plate.*—Embracing all glass cast as the last but not ground or polished.

3. *Window Glass.*—Embracing all glass blown in cylinders, and afterward cut and flattened out and polished while hot. Used for glazing, pictures, mirrors, etc.

4. *Crown Glass.*—Embracing glass blown in spherical form and flattened to a disk shape by centrifugal motion of blowing pipe.

5. *Green Glass.*—Embracing all the commoner kinds of glass, though not always green in color. It is used in the manufacture of bottles, carboys, fruit jars, etc.

6. *Lime Flint.*—Embracing the finer grades of bottles used for the prescription trade, tumblers,, certain lines of pressed tableware.

7. *Lead Flint.*—Embracing all the finest products of glass manufacture, as fine cut glass, tableware, optical glass, artificial gems.

Or the classification may be given as plate, window, green, and flint.

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1. Mineral Industry, Vol. 8, pp. 244-245; 1899.

The proportions by weight of the different ingredients are shown in the following table from Linton.

	Plate glass	Window glass	Green bottle	Lead flint
Sand (SiO_2)	100	100	100	100
Salt cake (Na_2SO_4)	..	42	38	..
Soda ash (Na_2CO_3)	36	..	..	..
Limestone ($Ca\ CO_3$)	24	40	34	..
Carbon (C)	0.75	6	5	..
Arsenic (As_2O_3)	1	2	..	0.15
Potash (K_2CO_3)	..	..	..	34
Red lead ($2PbO+PbO_2$)	..	..	..	48
Niter ($NaNO_3$)	..	..	..	6
Manganese (MnO_2)	..	..	..	0.06
Antimony (Sb)	..	..	..	0.02

From this table, sand is seen to be the most important component in quantity, forming 52 to 62 per cent of the mixture. It is therefore very important in any glass manufacturing center to have an available supply of suitable sand at reasonable cost. West Virginia on account of its cheap natural gas fuel has become one of the leading glass manufacturing states, and these plants are scattered all through its natural gas districts. In the state is found one of the purest limestones in the country, which is especially crushed at Martinsburg to supply this trade. The state also at a number of places has almost inexhaustible deposits of pure glass sand. There has thus developed a very prosperous sand industry which supplies the local factories and is shipped into other states.

Mr. E. F. Burchard[2] in a bulletin of the U. S. Geological Survey has given the requirements of a glass sand for different grades of ware and also suggests some simple methods for a preliminary examination of glass sands. His notes on these subjects are herein included and should prove of interest and value to those interested in glass sands:

"To the sand is due the absence of color (according to its purity), the transparency, brilliancy, and hardness of glass. In other words, the quality of the glass depends largely on the quality of the sand. For the finest flint ware,

2. No. 285, p. 453, 1905.

such as optical and cut glass, 'water whiteness', absolute transparency, great brilliancy and uniform density are required, and only the purest sand can be employed, since slight impurities, especially small quantities of iron, tend to destroy these effects. For plate and window glass, which are commonly pale green, absolute purity is not so essential, but generally the sand should not carry more than two-tenths per cent of ferric oxide. Green and amber glass for bottles, jars, and rough structural work can be made from sand relatively high in impurities. An excess of the chief impurity, iron, is usually avoided in the quarries by a careful selection of the whitest sand, although the whitest sand is not invariably the purest. Repeated washing tends to remove the iron. Clay materials are objectionable because they cloud the glass. Washing helps to remove them, since they occur usually in a very finely divided state. Magnesia, which is more apt to be introduced into glass materials through limestone than through sand, is troublesome because it renders the batch less fusible. If the sand is derived from industrial sandstone, the latter should be friable or easily crushed.

"In examining sand, in order to ascertain its value for glass making purposes, inspection with a magnifying glass is the best preliminary test. The following points should be observed: The sand should be nearly white in color; it should be of medium fineness (passing a 20 to 50 mesh horizontal sieve); the grains, should be uniform in size, even and angular, or less preferably, they may be rounded. A simple chemical test may be employed by heating the sand in a dilute acid. Effervescence indicates the presence of lime, loss of color shows the presence of clay impurities. Iron in the most minute quantity may be detected by dissolving sand in hydrofluoric acid and adding potassium ferrocyanide, which produces a blue precipitate if iron is present. Complete quantitative analyses as well as a furnace test should be made as a final determination of the character of a prospective glass sand. * * * * Sand uniformly finer than one-sixtieth inch is said to burn out in the batch and not to

produce as much glass per unit of weight as does coarser sand. In a mixture of coarse and fine sand the finer sand is liable to settle to the bottom of the batch thus preventing an even mixture of the materials and producing in consequence a glass uneven in texture.

BERKELEY SPRINGS.

The various glass sand deposits in West Virginia and the mills will now be described. The most important center is near Berkeley Springs in Morgan County where the Oriskany white sandstone near the summit of Warm Spring Ridge has long been quarried for glass sand.

Warm Spring Ridge extends from the Potomac river opposite Hancock Maryland, southwest for a distance of 8 or 10 miles with a direction N. 25° to 30° E., with an elevation of 1,000 to 1,100 feet decreasing to 800 and 700 feet at its northern end. It separates the valley of Sir Johns run at the west from Warm Spring run at the east. The town and summer resort of Berkeley Springs is located in the valley at foot of the ridge on the east and is reached by a branch of the Baltimore and Ohio railroad.

The crest of the ridge is composed of the thick stratum of white Oriskany sandstone, while the lower slopes to the east are composed of Hamilton and Chemung shales. The structure of this ridge, according to G. W. Stose[3], is part of a monocline between a massive anticline bringing up the Medina sandstone in Cacapon Mountain, one mile and a half to the west, and a sharp syncline of Carboniferous rocks forming Sleepy Creek Mountain, six miles to the east. As this sandstone is followed north into Maryland, it is a brown rather impure sand used only for building sand. The good sand extends southwest beyond Berkeley Springs, but in the counties further south much of the rock is high in iron and brownish or yellowish white in color. The present development extends from a point on the ridge three-fourths mile south of the Potomac river and the main line of the

3. U. S. G. S. Bull. 285, p. 473; 1905.

Baltimore and Ohio railroad, nearly three miles to Berkeley Springs.

PENNSYLVANIA GLASS SAND COMPANY.

Hancock Plant. The offices of the Pennsylvania Glass Sand Company, are located at Lewiston, Pa., with sales offices at Pittsburg and Philadelphia. The Hancock plant is located one mile west of Hancock station of the Baltimore and Ohio railroad, and the quarry is three-fourths mile southwest of the mill.

The Hancock mill was started 40 years ago but was rebuilt in 1905, and up to 1903 the corporate name was the Hancock White Sand Company. The plant is built in two sections ,one devoted to the preparation of glass sand, and the other contains the pulverizer equipment for crushed sand. Both are substantial frame buildings, equipped with modern machinery for the preparation of sand products.

The sand and sandstone from the quarry are brought down an incline tram road in mine cars hauled by a small locomotive, and dumped into storage bins. A large spring comes out of the mountain back of the plant which furnishes an abundant supply of water for the mills. The water supply is a most important requirement in glass sand mills, as it must be free from clay or mud and iron. The sand plants in the Berkeley Springs and Hancock area are especially favored in the water supply which comes from the numerous springs of the Warm Spring Ridge forming in the valley to the east Warm Spring Run. In the proper washing of glass sand a very large quantity of water is required.

The sandstone at the Hancock plant quarry is very friable so it is readily crushed in an ordinary 8-foot wet pan under rotating heavy wheels or mullers, similar in construction to those used in potteries or sewer pipe works. After crushing, the loose sand with its clay and other impurites is conveyed with water into a circular rotating riddle or screen of 16 mesh, and then through a second similar screen. The coarsely screened sand is carried by a trough with large sur-

plus of water into the washing department which consists of a series of inclined wooden boxes or troughs, 10 to 12 feet in length. Each alternate trough contains a rotating screw conveyor with wide blades which carry the sand to the top where it is discharged into the next trough without a conveyor and is washed to the bottom, there passing into the next conveyor trough.

In the Hancock mill there are five conveyors to one wet pan and screens, and the sand leaves the fifth conveyor free from the yellow clay. The loss of this clay is clearly seen in the change of color of the water-sand mixture in the different conveyors. The liquid has a muddy yellow or brown color in the first conveyor, and somewhat lighter color in the second, while in the fifth the water is clear with the pure white sand in it.

Since the rock at this quarry contains a considerable quantity of small flint pebbles, and washed sand from the last conveyor is carried into a third circular screen which separates these pebbles from the sand. The white sand free from pebbles is carried by conveyors to bins above the drier. The Cummer hot air drier used at this plant with coke fuel is a 22-foot cylinder which has a capacity of 120 tons in 10 hours. The sand from the drier is screened again through a 20 mesh screen and taken in elevators and conveyors to the bins from which it is loaded in bulk in box cars.

The float sand and clay is sold to fire brick factories, while the more impure sand is used as engine sand. The small pebbles from the third screen find a ready sale for use in pebble asphalt roofing. At the Hancock plant there are two sets of wet pans, screens, and washing conveyors, or in other words it is a two mill plant. The capacity of the plant is 150 tons daily of No. 1 glass sand, requiring for the machinery 60 to 70 H. P.

A sample of this No. 1 sand was analyzed in the Survey laboratory with the following result:

	Per cent.
Silica	99.60
Iron oxide	0.0286
Alumina	0.4214

Pulverizing Mill. One of the very interesting parts of this plant is the pulverizing mill, known as the Potomac Pulverizing Plant, where the sand is crushed to a flour of various grades of fineness.

The equipment includes two tube mills, 24 feet long and 6 feet diameter, filled 1-3 full of flint pebbles. The sand from the glass sand plant is brought over in conveyors into these mills and ground by the action of the pebbles in the rotating tube mills. The mills are lined with silica blocks weighing in all 12 tons and lasting about 10 months when they must be renewed. The lining and pebbles wearing down to a flour; but since they consist of very pure silica do not form any impurity in the crushed sand, and sold with the sand flour represent a low money loss.

The sand is ground so as to pass through 90, 100, 110 mesh screens and the material is used for paint, scouring and polishing powders and for soap. One mill has a capacity of 18 tons of sand flour in 10 hours, when crushed to pass a 110 mesh screen; or 10 to 12 tons with 140 mesh screen. For certain special uses as silver polish the sand is crushed to pass a 260 mesh screen. With this fineness one mill will only yield about 150 pounds in 10 hours.

Quarry. The quarry of the Hancock plant is located near the top of the mountain, three-fourths mile from the mill and 280 feet above the Baltimore and Ohio railroad track. The whole top of the mountain is composed of the Oriskany sandstone filled with casts of fossils typical of the Oriskany. The same formation extends down the mountain slope to the east while at the West is the Lower Helderberg limestone through which a tunnel was driven to reach the sandstone.

The sandstone on outcrop is often quite hard and compact having nearly the appearance of a quartzite, the grains of the rock being cemented by silica. In the quarry the rock is very friable often breaking into sand under the sledge. Pockets of loose white sand are also found. Very little blasting is required except to loosen large portions of the wall. The larger blocks are broken by sledge, and much of the material is shoveled into the cars. According to Mr. Stose practically

all the sand grains from the quarry will pass a 40-mesh sieve and 25 per cent will pass a 60-mesh sieve. Certain portions of the ledge contain small milky white pebbles forming a fine conglomerate.

The quarry is worked in a north and south direction with a dip of 45 degrees to the southeast, so that the blocks loosened by a shot or by wedge roll down the slope to the bottom of the quarry. It was formerly worked by tunnels, but now is a large open cut or pit. It is 370 feet long, 120 feet wide, and 100 feet deep to the main floor of the quarry, but a portion of the quarry near the entrance of the tunnel is worked 25 or 30 feet deeper, the sand being drawn up an incline to the main track level.

The stone lies under little or no cover, in a few places it is covered by two or three feet of clay. The top of the sandstone is 30 feet above the top of the quarry which would give an exposed thickness at this place of 160 feet but the quarry is not yet to the bottom of the sandstone.

Berkeley Plant. The second plant of the Pennsylvania Glass Sand Co., is located four miles from Hancock up the Berkeley Springs branch of the Baltimore and Ohio railroad. This is a two mill plant similar in plan to the Hancock plant only built in more compact form, and a jaw crusher is used in preliminary crushing of the quarry stone. The sand is dried in a steam drier with 7,000 feet of heating surface and a capacity of 10 tons an hour. The capacity of the plant is 180 tons of glass sand daily.

The following analysis of the No. 1 sand was made in the Survey laboratory:

	Per cent.
Silica	99.30
Iron oxide	0.0314
Alumina	0.5186

Quarry. The quarry is located 975 feet west of the mill and was opened in 1906. It is approached by an open cut 20 feet long and 8 or 10 feet wide which passes through a black shaly limestone and yellowish sandstone to the open quarry where the face of sandstone is 80 to 100 feet high.

The sandstone is apparently harder than at the other quarry though much of it breaks and crumbles in a similar manner. The rock dips 50 degrees a little south of east and the quarry is worked toward the west. The sand is loaded in cars which pass down an incline track to the mill located a short distance west of the railroad and reached by a short switch.

WEST VIRGINIA AND PENNSYLVANIA SAND CO.

West Virginia Plant. The offices of the West Virginia and Pennsylvania Sand Co., are located at Baltimore, Md. The West Virginia plant of this Company is located 1 1-2 miles south of the Berkeley plant described above. It contains three mills, each consisting of a wet pan, one screen, five washing conveyors, and the stone is first run through a jaw crusher. The Keystone plant located a short distance from the first contains one mill. The sand in the West Virginia plant is dried in Cummer rotary drier which is 28 feet long.

The composition of the No. 1 and No. 2 sand from this plant is shown by the following Survey analyses:

	No. 1 sand.	No. 2 sand.
Silica	98.99	98.85
Iron oxide	0.0383	0.0543
Alumina	0.7717	1.0457

Quarry. The old quarry located a short distance west of the plant was opened in the spring of 1900. It shows a face of 140 to 160 feet with 6 to 12 feet of surface stone, much harder than the main quarry rock and which is not used. The rock dips 40 degrees southeast and trends N. 20° E.

In 1904 a new quarry was opened to the south of the last which shows 125 foot face and is now 60 to 80 feet wide with room for 8 to 10 tracks. The floor of the quarry is 200 feet above the floor of the mill. In the quarry red clay seams are found along the joint planes which are one to five feet apart. The stone is worked under the ledge and then shot down in large masses. There are boulders of hard flinty sandstone

through the main rock, but these are not used as they tend to grind to a flour.

Pittsburg Plant. The Pittsburg plant of the West Virginia and Pennsylvania Sand Co., is located three-fourths mile south of the West Virginia and Keystone plants. It is equipped with Blake crusher and has two mills, one with five and the other with six washing conveyors. The sand is dried in a Cummer drier 24 feet long and 6 feet diameter. The glass sand is stored in two vertical round steel tanks resting on concrete foundations, and hold 25 cars or 300 tons. The daily capacity of the company plants is 400 tons of sand daily.

Quarry. The quarry in the white Oriskany sandstone which supplies this plant was opened in fall of 1905. It shows a face of white rock 100 feet high and is worked in a north and south direction with a length of 180 feet. The rock dips 50 degrees to southeast, and the stone is loaded into cars which pass down the incline to the mill.

Pulverizing Mill. This same company owns a pulverizing mill located near the northern edge of town of Berkeley Springs and operated under the name of the National Mining and Milling Co. It was formerly equipped with five short ball mills grinding the sand by action of the rolling steel balls, but their use has been abandoned. The sand is now ground to a flour in one pebble mill 25 feet long.

SPEER WHITE SAND COMPANY.

This company built a large modern plant in 1905, one half mile north of Berkeley Springs and owns five acres of sandstone. The plant cost $40,000, and has a daily capacity of 140 tons. It is equipped with a double mill and the sand is dried in a steam drier. Mr. Speer of this company was one of the original manufacturers of glass sand in the Berkeley Springs district but sold his former interests and was out of the field for many years.

The number 1 sand from this plant has the following composition according to the Survey analysis:

	Per Cent.	Sterling Plant
Silica	99.860	98.84
Iron oxide	0.068	0.017
Alumina	0.179	0.143

BERKELEY SPRINGS SAND COMPANY.

This company built their plant in the town of Berkeley Springs in 1891 and at present time it is the last plant to the south on the ridge, though a new company has an option on a tract south of town and is planning to erect a mill.

The equipment includes an 8-foot wet pan, four washing conveyors and the sand is carried by a big reel with perforated buckets attached to the arms, and dried in two driers 20 feet long. The capacity of the plant is 85 tons of No. 1 glass sand daily.

The quarry is located across the county road, nearly half way up the ridge and shows a face of rock 120 feet high. It is worked in an open cut 180 feet long and 50 feet wide and is reached by a short entry passing through a hard yellowish outcrop of the sandstone.

The following analyses were made in the Survey laboratory of the glass sands from this plant:

	No 1 sand.		No. 2 sand.
Silica	99.580	99.120	99.580
Iron oxide	0.068	0.154	0.018
Alumina	0.199	0.211	0.153

From the above descriptions of the Berkeley Springs-Hancock glass sand district in the Oriskany white sandstone, there are seven plants with 13 mills and a daily capacity of 955 tons of No. 1, glass sand. There are also two pulverizing plants with three tube mills grinding the sand to a flour.

GREAT CACAPON SILICA SAND COMPANY.

The Great Cacapon Silica Sand Company of Pittsburg opened a quarry in the Medina white sandstone in 1904 on the west slope of Cacapon Mountain one mile and one-half west of Berkeley Springs. The following description of this

quarry is given by Mr. W. G. Stose[4]: "A hole 20 feet wide and 150 feet long has been quarried into the face of the hill, exposing low westward dipping beds of hard quartzitic sandstone somewhat stained with iron. The quarry is admirably located for handling the product by gravity 500 feet deep down the slope, on a grade of about 20 degrees to the railroad (B. & O. main line.) At the bottom of the incline a mill has been constructed with the different compartments arranged in terrace form, utilizing gravity in crushing, washing, drying, and storing the product ready for loading on the cars.

"The rock is so hard, even at the depth attained, that it must all be crushed and thoroughly ground, and even then it does not separate into grains, but breaks into fragments of various sizes, much being reduced to a powder. The product, therefore, is not so suitable for high-grade glass, and the greater amount of grinding necessarily adds to the cost of production. The surface appearance of the rock is also not favorable, as it has a grayish cast with numerous iron stains, but an analysis was not obtained and its exact composition is not known. The successful operation of this mine, although so admirably situated for a gravity plant, is very dubious on account of the character of the rock, and further mining on this outcrop is not to be encouraged."

The chemical analysis of this glass sand shows a very pure rock and would indicate that it was of more value than given in the above quoted paragraphs.

	Per cent.
Silica	99.86
Iron oxide	0.06
Alumina	0.23

WHITE ROCK SAND COMPANY, HOLMES, WEST VIRGINIA.

The offices of the White Rock Sand Company are located at Oakland, Maryland, and the plant is located on the main line of the Baltimore and Ohio Railroad, one mile west of

4. U. S. Geol. Survey Bull. 285, p. 475; 1905.

Corinth or three miles east of Terra Alta in Preston County. The plant was started in November 1906, and doubled in size near the close of 1907.

The sandstone is crushed in a Jeffrey pulverizer then in an 8-foot wet pan. It is washed by three conveyors and passes through a circular screen with 16 mesh and seven feet in diameter, and dried in a steam drier. Water for washing is supplied by Snowy Creek and also two smaller streams, Spring and Philadelphia runs. The capacity of the plant is 200 tons daily, the pure white sand is sold as glass sand, and the slightly colored sand is shipped for building sand.

The quarry is located back of the mill and connected by an incline track. The sandstone is 60 to 80 feet thick but much of it is too impure for glass sand. The working quarry is 22 feet high and worked in a northeast direction, the stone dipping to the southeast. At the bottom of the quarry is a 3-foot stratum of very coarse sand filled with clear translucent flint pebbles; above this layer come 4 feet of coarse sand, then 2 feet of finer gray to white sand, and above this 3 feet of pink colored sand, overlaid by 4 feet of pink and white sand The work last year was mainly on outcrop material which was sold as building sand, but a better grade of sand was found farther in the hill, also above the top of the present quarry.

The selected sand from this plant has the following composition according to the Survey analyses:

	Per cent.	Per cent.
Silica	98.20	98.95
Iron oxide	0.0295	0.048
Alumina	1.5705	1.112

The following survey analyses show the composition of the pink sand and the No. 2 glass sand:

	Pink sand.	No. 2 sand.
Silica	97.10	98.60
Iron oxide	0.0457	0.045
Alumina	2.7743	1.465

The rock is friable and readily broken and forms a uniform angular sand which has been successfully used at a

number of glass plants. The rock dips to the southeast under the coal mined near Corinth which is regarded as the Lower Kittaning vein. The sandstone then would correspond to the Homewood of Pennsylvania the upper member of the Pottsville Conglomerate, and is the same horizon as at the next two plants to be described.

DECKERS CREEK STONE AND SAND COMPANY.

The plant of the Deckers Creek Stone and Sand Company, is located on Deckers Creek at Sturgisson, nine miles southeast of Morgantown on the Morgantown and Kingwood railroad.

The equipment includes one crusher, one eight-foot wet pan, screens, and eight washing screw conveyors. The sand is dried in a Ruggles-Coles rotary drier, 25 feet long and 6 feet diameter. The capacity is 60 to 90 tons of sand daily, and both glass and building sand are prepared for market.

The following analyses of the sand from this plant were made by the Survey:

	No. 1 sand.	No. 2 sand.
Silica	99.15	98.82
Iron oxide	0.0383	0.1183
Alumina	0.6517	0.8217

The quarry is located at the top of the hill back of the mill 620 feet higher than floor of the mill and the stone is hauled in cars down an incline track, 1,820 feet long. The sandstone is 40 to 50 feet thick of which 35 feet is worked. The upper portion somewhat higher in impurities than the lower is sold for building sand, while the lower ledges form a high grade glass sand. The cost of plant and equipment is over $80,000, and the company has found a good demand for their products. The geological horizon appears to be the same as the Holmes plant near Terra Alta, the Homewood sandstone.

Plate XIV.—High School at Parkersburg, Wood County. Stone from Keenan Quarry in Marietta Sandstone.

SILICA SAND COMPANY AT CRADDOCK, W. VA.

The Silica Sand Company opened in 1905 a glass sand quarry at Craddock on the Weston and Pickens branch of the Baltimore and Ohio railroad up the Buckhannon river in Upshur County, 47 miles from Weston or 4 miles northwest of Pickens.

The equipment includes an Austin No. 5 rotary crusher, 8-foot wet pan, five washing screw conveyors. The sand is dried in a Cummer drier, 22 feet long, and screened through 8 and 14 mesh screens. 28 men are employed, and the daily capacity is 120 to 150 tons of glass sand and 15 tons of pebbles and coarse gravel used for concrete. The storage capacity is about 30 cars, the sand being held in a steel tank of 400 tons capacity, and bins holding 80 tons with a large floor space for the wet sand. The mill is enclosed in a large frame building 20 feet high from the boiler floor to the crusher floor and the elevator portion 10 to 15 feet higher. The lower floor is 18 feet above the level of the B. & O. track at the station.

The composition of the sand is given in the following Survey analyses:

	Unwashed.	Washed No. 1 sand.
Silica	97.66	99.20
Iron oxide	0.1291	0.0708
Alumina	2.1209	0.6492

The quarry is 398 feet above the lower floor of the mill, or 415 feet above the railroad and the top of the Craddock gas well. The floor of the quarry is 18 feet above the top of the incline track which is 1,450 feet long to the mill. A thin coal vein about one inch thick covered by 6 or 8 feet of white clay is found below the sandstone and 85 feet lower is a coal vein, said to be 3 feet thick and formerly mined. The sandstone appears to be the Homewood or Roaring Creek.

The quarry face runs nearly north and south and is worked to the west under shallow cover, and is 45 feet wide. The manager of the plant, Mr. Redebaugh states that up to

the close of 1907, 36,000 tons of sand had been removed. A section of the quarry shows,

	Feet.
Clay and soil cover	2 to 3
Solid white to gray sandstone	10
Irregular breaking and cross bedded sandstone	12
Pebble or conglomerate sandstone	3

The sand is bluish-white in color and near outcrop weathers to a light brownish color. It is friable though in unweathered blocks has a firmer texture and much of the rock must be crushed. It is worked in an open cut in benches and direct natural gas power is used in the drills. Cable haulage is used on the incline, and natural gas is used throughout the plant. Near the close of the year 1907 the mill was destroyed by fire, but plans have been made to rebuild at once.

Two miles further southeast on the railroad from Craddock at the station of McCauley now called Silica, is the plant and quarry of the Enterprise Silica Sand Company of Bellaire, Ohio. This plant was built in 1904 with one mill, and quarry in similar rock to that at Craddock. It was not in operation during 1907.

To illustrate the demand for glass sand in a glass factory the State Window Glass Company of Buckhannon operates a 36 blower tank and used the Craddock sand. They used when running at full capacity 150 tons of sand and 25 to 30 tons of Martinsburg limestone a week. The glass making season extends over a period of 6 months from September 1st, to June 30th. If operated at full capacity during this period, they would use in a year (6 months operation) 3,600 tons of glass sand.

CHAPTER XVIII.

MARTINSBURG SHALES AS A SLATE PROPOSITION.

The Martinsburg shale in 1904 and 1905 attracted some attention as a basis of a possible slate industry. A half dozen companies were organized and options taken on lands available to the railroad. A considerable amount of money was expended and finally the companies allowed their options to expire and interest waned. The most extensive development was made by the Shenandoah Slate Company of Washington, D. C., which opened a quarry 65 feet in depth and equipped a small mill with sawing, grinding, and polishing machinery. The slate was used in interior construction work with satisfactory results. Large slabs were obtained and took a good polish. As the writer stated in Volume III of the Survey Reports, our laboratory tests showed the material defective for roofing slate as it soon showed a tendency to crack and disintegrate and blocks left out in the weather cracked and scaled. In that Volume the following analyses of the better grades of this shale were given, together with analysis of the famous Peach Bottom slate of Pennsylvania:

	M. Tabler farm	L. Tabler farm	Shenandoah quarry	Peach Bottom Penna.[1]
Silica	56.67	56.29	53.30	55.88
Alumina	19.52	17.85	18.16	21.85
Ferric iron	3.06	2.41	1.95	....
Ferrous iron	4.00	4.58	4.58	9.03
Lime oxide	2.23	2.88	4.89	0.155
Magnesium oxide	1.94	2.63	2.65	1.495
Sodium	0.96	1.02	0.82	0.460
Potassium	3.08	3.56	3.70	3.64
Water	0.36	0.31	0.68	....
Titanium	0.86	0.78	0.72	1.27
Phosphorus	0.45	Trace	0.24	....
Sulphur	0.99	1.28	0.77	....
Loss on ignition	5.56	6.84	7.36	....
	99.68	100.43	99.82	....

In 1906, since the publication of Volume III of this Survey, Mr. T. Nelson Dale published a bulletin on the Slate deposits of the United States, issued by the United States Geological Survey, and in this report gives the results of his investigation and study of the Martinsburg shale or so called slate (Bulletin No. 275, pp. 119-122).

On account of the great interest which was taken in this shale as a slate proposition, and the fact that a number of the people who own these slate farms still hope to see this industry opened, it has been deemed advisable to reprint Mr. Dale's contribution in this report. While the investigation condemns the shale as a slate proposition, it must be remembered as explained in detail in Volume III that this shale will form a valuable addition to the mineral wealth of this area in connection with the adjoining limestone for Portland cement manufacture.

THE MARTINSBURG SHALE OR SLATE IN WEST VIRGINIA.

By T. NELSON DALE.

(A reprint of article from Bulletin 275 of U. S. Geological Survey.)

This recently prospected slate district lies near Martinsburg, in Berkeley County, within the geological belt desig-

1. By McCreath quoted by Dale, U. S. G. S. Bull. 275, p. 34.

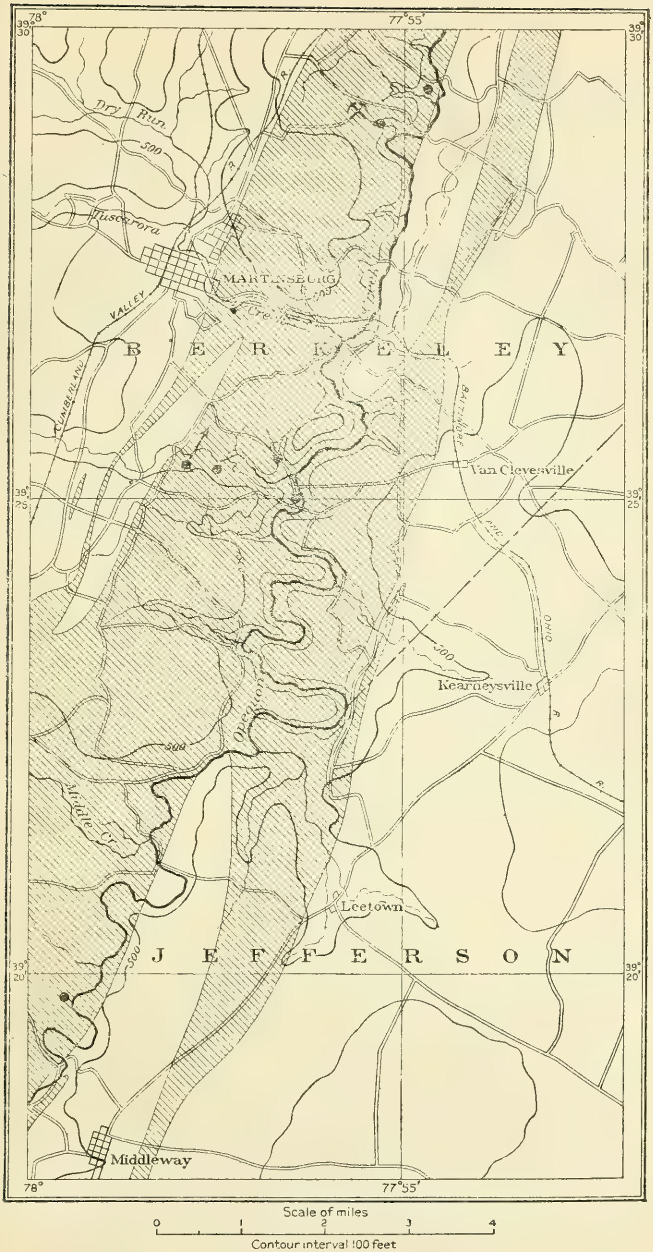

Fig. 13. Map of slate region about Martinsburg (Loaned by U. S. Geological Survey). Shading represents area underlain by Martinsburg shale. Slate quarry is shown by crossed hammers; slate prospects by round dots; strike of commercial slate by arrow.

nated in the Harpers Ferry folio of the United States Geological Survey as "Martinsburg shale." Brief preliminary notices of it have appeared in Bulletin No. 213 (p. 363) and again in Bulletin No. 260 (p. 538). This belt lies about 13 miles west of the Blue Ridge and mostly on the western side of Opequon Creek, a small tributary of the Potomac. It measures at least 14 miles in length from north-northeast to south-southwest and from 2 to 3 miles in width. The accompanying map (fig. 13) shows the geological relations and the principal outcrops. This shale and clay-slate formation, estimated at from 700 to 1,000 feet in thickness, is of Ordovician age and overlies the Cambro-Ordovician "Shenandoah limestone" in a series of folds represented in the folio as overturned to the west. The rock is generally a dark-grayish shale, weathering into a yellowish or white clay, known locally as "soapstone." At several points, usually near the Opequon or its tributary "runs," where the mass has been denuded of its weathered zone, it has a well-marked easterly dipping (exceptionally westerly) slaty cleavage, crossing the bedding at various angles, and pieces, when struck with a hammer, give the typical ring of slate. The slatiness of the formation is, however, inconstant.

The only quarry yet opened is that of the Shenandoah Slate Company, about 3 miles northeast of Martinsburg, near a small run flowing into the Opequon. When visited in May, 1904, the quarry measured about 100 feet along the strike, 70 feet across it, and 75 feet in depth, of which the "top" took up 25 feet. The bedding strikes N. 25° E., dips about 15° E. The cleavage, with the same strike, dips 75° E. There are joints striking with the cleavage and dipping 35° E., dip joints striking N. 50° W., dipping 90°. The beds are small and are separated by darker ribbons. The thickest bed exposed measured 3 feet, 6 inches. A diamond drill core from down to 40 feet below the bottom of the quarry shows several 3-foot beds.

The slate is black, with a slightly brownish hue. The texture is somewhat fine and the cleavage surface roughish without any luster whatever. The material is carbonaceous

rather than graphitic, contains a little magnetite, shows pyrite on the sawn edge, effervesces with cold dilute hydrochloric acid, but less in the ribbon, is somewhat sonorous, and has an argillaceous odor. Under the microscope it shows a matrix consisting of carbonate and carbonaceous matter, and therefore without aggregate polarization, but a cleavage consisting in the parallel arrangement of the carbonate and carbonaceous matter in alternating bands. A very carbonaceous bed (ribbon) crosses the cleavage at an angle of 36°. There are abundant angular quartz grains up to 0.05 millimeter; scales of chlorite interleaved with muscovite, and some of muscovite only; spherules of pyrite up to 0.01 millimeter, numbering about 240 per square millimeter. Rutile not observed. The amount of carbonate differs in different beds. It may be so abundant as to obscure completely the sericitic matrix. Some of the sections parallel to the cleavage show almost as much muscovite as carbonate and, curiously, a faint aggregate polarization parallel to the bedding or the grain.

The constituents of the Shenandoah Slate Company's slate, arranged in descending order of abundance, appear to be carbonate, muscovite (in places almost equal in amount to carbonate), quartz, kaolin, pyrite, carbonaceous matter, chlorite, magnetite. This is a clay-slate. The amount of CO_2(carbon dioxide) in this slate was determined by Mr. George Steiger, chemist of the United States Geological Survey, at 1.94 per cent.

An analysis of slate from this quarry made for the company by Dr. C. W. Tilden, of Washington, shows silica SiO_2, 62.71; alumina Al_2O_3, 19.40, and lime CaO, 1.11 per cent. It is proposed to use the product of this quarry for mill stock, for which it seems better adapted than for roofing.

The following prospects were noted: One two miles south of Martinsburg, on John Rowe's land, where an opening 30 by 20 feet has been made. Bedding strikes N. 32° E., dips 60°—65° E.; cleavage strikes N. 23° E., dips 80° E. A 3-foot bed is in sight. Another opening has been made on the Opequon, on Light's land, a half mile southeast of Beddington (a little north of the north limit of map). Bed-

ding and cleavage strike N. 20° E., the former dipping 30° E., the latter 55° E. A 3-foot bed is in sight. Under the microscope this shows a faint aggregate polarization, fragments of feldspar, and rutile needles. At an opening on T. F. Bower's farm, about four miles northeast of Martinsburg, the cleavage strikes N. 27° E. and dips 73° W., but beddings dips east. Under the microscope this shows a faint aggregate polarization, but carbonate is unusually abundant and evidently obscures the cleavage. In the brook on John Shedd's farm two miles and a half south-southeast of Martinsburg the cleavage strikes N. 20° E. Under the microscope this shows a slight aggregate polarization and but little carbonate. Clay-slate has also been found on the McKown and Busey farm, two miles N. 10° W. from Middleway, in brook two miles and a half southeast of Martinsburg, and also on land of J. W. Snyder on the Opequon, three miles southeast of Martinsburg, and it will be found in many other places.

Although the proportions of carbonate and muscovite vary in these slates, none of them show a complete sericitization of the matrix. They are all clay-slates. The material can therefore hardly possess sufficient fissility or prove sufficiently strong or elastic to compete with mica-slates for roofing purposes. Furthermore, the amount of carbonate shown by the microscope, as well as the mode of weathering by the outcrops, indicates it probable discoloration on prolonged exposure, so that it belongs in the "fading" group of clay-slates. But these characteristics do not affect the serviceableness for indoor purposes.

CHAPTER XIX.

THE PROPERTIES OF BUILDING STONE.

Stone of the same and different kinds vary in quality according to definite characters or properties which they possess. The value of stone as building material will be determined by these properties which will now be discussed under the following heads:

1.	Mineral composition	8.	Hardness
2.	Color	9.	Specific Gravity
3.	Structure	10.	Weight per cubic foot
4.	Strength	11.	Elasticity
5.	Texture	12.	Durability
6.	Porosity	13.	Workability
7.	Nature of the bond.	14.	Availability.

1. MINERAL COMPOSITION.

Rocks are composed of minerals, and the value of a building stone depends to a large extent on its mineral composition. Some minerals are harder and more durable than others. All minerals are subject to change through weathering. Some like quartz are so slightly altered that they are described as unchangeable, others like feldspar alter to softer minerals like kaolin, and crumble. Iron, lime, and to less extent dolomite are subject to solution and removal.

Rocks therefore composed of minerals are subject to change, the rapidity of the action depending on the kind and amount of the minerals present. A quartzitic sandstone would be more durable a sa rule than a feldspathic granite, and both more durable than a limestone, but the nature of the bonding material would be more important.

The classification of the rocks into different groups depends in large part on the mineral composition. Sandstones are composed mainly of quartz; limestones, of calcite; shales of clay which has a base of kaolin. In the classification of igneous rocks certain minerals are regarded as essential, while a variety of accessory minerals may be present. Thus a granite is composed of three essential minerals, feldspar, mica, and quartz, but in addition there may be garnet. magnetite, zircon, apatite, hornblende, etc., as accessory minerals. Sandstone while composed essentially of quartz, may have feldspar, mica, iron oxides, pyrites, etc., present.

2. COLOR.

Rocks being found in different colors, the particular color desired in a building stone becomes a matter of personal selection or fashion, though careful attention should be directed to permanency of color.

In the igneous rocks, the color is due to a combination of the different colors of the constituent minerals, and is a composite rather than a simple color.

Granite composed of feldspar, quartz, and mica has its color determined by these minerals. A white feldspar with white mica and quartz gives a light gray or nearly white rock. When the mica is black biotite the color is gray, the depth of the shade depending on the size of the crystals and the amount of the dark colored mica. When the feldspar is red or flesh colored, the granite is red.

Diorite on account of the green hornblende has a greenish color, and this group of rocks is often called the green-stones. Serpentine is a green stone due to the green mineral serpentine. The basic rocks like gabbro, diabase, basalt are dark in color almost black due to the dark colored mineral pyroxene, and the absence of lighter colored minerals.

The color of the igneous rocks is therefore determined by the different colored minerals composing them. In the sedimentary rocks the color is often determined in the same way by the color of the predominant mineral. Thus calcite

and dolomite minerals having when pure a white color, pure limestones and dolomites are white.

The presence of organic matter may darken these otherwise pure rocks, giving blue or even black limestones. These dark limestones when calcined have the organic matter burned out and make white lime. If iron is present in any quantity the color will be modified by this element giving red, blue, green, etc.

Pure quartzitic sandstones are white or nearly so, but most sandstones contain iron so that they occur in a great variety of colors, white, gray to buff, red, yellow, brown, blue, green, etc.

Iron is one of the greatest coloring substances found in the rocks of the earth's crust. It exists in various forms, but its oxides give the great variety of colors. Perhaps the most important is the peroxide or ferric oxide of iron, Fe_2O_3, which gives a red color. The protoxide or ferrous oxide, FeO, alone gives a greenish color, and the combination of the two oxides gives a great variety of colors. Manganese gives a purple color. In quartz it gives the amethyst.

The color of building stone may vary from one quarry to another, or in the same quarry, or even in the same ledge in a quarry. The colors vary in permanency but most stone changes in color after exposure to the air. The color of stone at surface of quarry is different from that below. A freshly quarried stone is usually darker than the exposed rock due to its moisture which is later lost by evaporation. On the exposure to the air there is often a further change in color. This may be slight or there may result a complete change in color.

It becomes important for architectural reasons to determine the permanency of color. A stone which changes irregularly on exposure to air, causes a spotted appearance in the building which may become unsightly. Some years ago in eastern cities brown stone was the popular stone in the large residences. This stone was hard to work and also more or less distant from the cities where used, hence it

was costly, and brown stone fronts became synonyms of wealth.

The construction of solid blocks of buildings of this stone gave a somber or even gloomy effect which was apt to be tiresome to the eye so the fashion has declined. The white marble rows of some cities on the other hand proved glaring and injurious to the eye. Again a combination of green stone front adjoining a brown stone and this next to a white marble front, gave a checkered appearance more offensive than either of the above conditions. The combination of stone in adjacent buildings should be determined by colors which would harmonize if beautiful effects are desired.

In the use of stone for trimming of a house constructed of other material one person may prefer a selection of stone that will blend in color with the main part of the building, while another prefers contrast. The former would use a brown or red stone with red brick, while the latter would select gray, blue or white.

It is this difference in tastes that causes a demand for stone of different colors, thus permitting stone to be shipped long distances from the quarry coming into direct and successful competition with a home product. Stone is shipped from some West Virginia quarries to New York, Philadelphia, and Baltimore, there finding a constant demand. While color does not account entirely for the successful sale of this stone, it is a very important and essential consideration.

A loose, open textured stone, affords ready access to circulating water with its oxidizing effects and is more apt to be irregularly colored than one of close grain. A greater objection is noticed on exposure of the open textured stone in the wall of a building, by the lodgment and retention of particles of dust, soot, etc., in the pores so that the stone rapidly darkens with age. It is almost impossible to clean such a stone while a close grained stone darkened by dirt can be cleaned and its freshness restored. If the stone contains any bitumen or oil, this trouble is greatly augmented.

The iron colored stone is very liable to changes due to oxidation, but the ferric oxide is usually more stable and the color is more permanent. The light blue or greenish sandstones are especially liable to oxidation, becoming buff or light gray color.

The limestones of West Virginia used as building stone are grayish white to blue, while sandstones are found in nearly all colors: brown, red, blue, gray, green, yellow or buff, white, and in a variety of shades of these colors. All tastes and varieties of fashion in color, can be supplied from some of the quarries in the state.

Some of the sandstones show a distribution of colors through the rock in more or less wavy lines and are locally called **calico stone.** This distribution of color in veins is due to percolation of water through the rock, dissolving iron in one place depositing it in another. Such an effect is often seen in quarries near joint planes and fissures.

Building stone will show a variation in shade of color when finished in different ways by tool dressing. A smooth polished stone surface is usually darker than the rough surface, due to the removal of irregular projections which reflect the light. With this loss of reflection there is a corresponding increase in light absorption giving to the eye the sensation of deeper or darker color.

Stone on exposure in a building sometimes shows defects of staining by formation of white or other colored coatings over the surface of the stone. Iron oxides or pyrites by leaching leave a rusty iron streak across the rock. Soluble salts such as, lime sulphate or carbonate, magnesia, alum, etc., present in the rock may be brought to the surface by capillary water or free moisture which on evaporation leaves the soluble salts as a deposit. This is a serious defect in appearance of the stone. Analysis and careful examination have shown in many cases that the troublesome coating has come not from the stone but from impurities in the lime or cement used as mortar between the blocks of stone. In the construction of walls, careful attention should be given to the character of the mortar used if this trouble

of discoloration is to be avoided. Until the mortar has been carefully examined and tested, these coatings should not be attributed to defects in the chemical composition of the stone.

3. STRUCTURE.

Sedimentary rocks are stratified or divided by parallel planes into layers or strata due to the sorting power of water at the time the sediments were deposited. These planes of stratification are known as the rift or the bed planes. When these bed planes are well developed and close together, a banded rock is formed, often with flat shining mica flakes covering these planes giving the silver seams of the quarrymen. They are lines of weakness in the rock and may open under weathering action causing the rock to split and scale. This effect is more noticeable when the stone is set on edge or at right angles to the direction of the bed. They are also aids to the quarryman in splitting out blocks of varying thickness from thin flag stone to large building blocks. When these planes are well developed the blocks will break with a smooth surface not requiring further tool dressing.

Joint Planes.

Joints are division planes through the rocks and across the stratification beds, and were formed subsequent to the deposition of the sediments and were probably caused by the shrinkage during the consolidation of the sediments into rocks. There are usually two sets of joints at right angles to each other or nearly so, and there may be other sets running at different angles. The main or master joints may sometimes be traced for long distances through the rocks, nearly parallel to each other, while the minor joints vary in extent and direction.

The joints in a quarry rock are both advantageous and sources of injury. The rock has a tendency to separate

along these planes thereby giving access to water which hastens the work of weathering and solution, and in winter by the freezing of this water, the rock is broken near these planes. In limestone the joint planes may be widened into fissures by solution, leaving cavities often filled with dirt and clay. The water penetrating the joint planes, carries iron and other minerals staining the rock for some distance. There may also be a deposition of mineral matter, and the joints have a coating of crystal lime. etc.

If joints were absent it would be very difficult and expensive to quarry the stone. so they are aids to the quarryman. The size of the blocks available in the quarry will be determined by the distance between the joints. Where these planes are close together or irregular in direction the blocks will be small and angular and thereby worthless as building stone.

In rocks which have been subjected to great pressure in the earth's crust, planes of easy fracture are developed at right angles to the direction of the pressure and are known as cleavage planes. Where these planes are well developed the rock breaks into thin plates or laminae and is fissile in character. It is this structure that makes roofing slate. In the unaltered sedimentary rocks the cleavage structure is absent.

4. STRENGTH.

The strength of a building stone is measured by its ability to withstand the various stresses to which it is subjected. It depends on the mineral composition of the rock, as softer minerals form a rock of lower strength than harder ones. Quartzitic sandstone, other factors being equal, is stronger than a limestone.

The strength of the stone will depend on the texture, or the size and shape, and distance apart of the mineral particles, and especially on the nature of the cementing material or bond. It will also depend on the structure of the rock, the number and distance apart of sedimentary planes,

and for this reason the strength will usually be greater when pressure is applied parallel to these planes than when at right angles.

The absence of cleavage or fissile planes, and lines of fracture will give greater strength to the rock. A building stone block may be of lower strength than the stone in a quarry due to careless work in dressing the stone. Lines of fracture plain to the eye or more often incipient may thus be introduced by hammering and pointing the stone.

The strength may be greater after the stone has seasoned than when it is first quarried, due to the hardening of the cementing material on evaporation of the quarry moisture or by absorption of carbonic dioxide or oxygen from the air.

Igneous rocks on account of the interlacing character of the minerals and the firmer consolidation under heat and great pressure, usually have higher strength than sedimentary rocks. The strength of the stone to resist various forms of stress may be determined by laboratory tests as discussed in a subsequent chapter. In this way different kinds of stone and stone from different quarries can be compared.

5. TEXTURE.

The texture of a rock refers to the size, form, and arrangement of its consistent particles. A rock may be loose and open, or close and compact in texture, as determined by the size of the grains and amount of consolidation. Large particles will give a coarse texture to the rock while small grains will usually make a compact rock. In the conglomerate, the pebbles are large as compared with the sand grains in sandstone grit.

Where the rock is composed of a mixture of large and small particles the texture will be more compact and the rock stronger since the smaller particles fit in between the larger making a more solid aggregate. In any fragmental rock where the grains are held together by cementing ma-

terial, the smaller grained rock will usually be stronger for a larger amount of surface is exposed to the cement.

The shape of the particles is also important. Rounded grains will usually form a rock of lower strength than one with angular grains, as the latter gives better hold for the cementing material. Flat grains are usually arranged in more or less parallel planes giving a banded character to the rock.

The closer the grains are together the greater the force of adhesion, and the stronger the rock. There will also be less space for water and air to enter resulting in less destructive effects of weathering. Where the spaces are filled with good cement, the closeness of the grains is of less importance.

If the minerals of a rock are segregated in bands or planes, this arrangement will tend to make the rock fissile and it will have a tendency to break along such planes. Gneiss thus differs from granite in the minerals, especially mica, being arranged or segregated along parallel planes giving the foliated appearance characteristic of this rock.

If a rock is composed of harder and softer particles the softer may weather out leaving the harder projecting thus giving a pitted appearance. Fossils in the rock are often softer than the main portion of the mass, and their surfaces may form lines of weakness so that they are dissolved or broken out causing a similar effect to the last.

Rocks according to their texture break in different ways. The kind of surface formed by breaking a rock is known as fracture, and the following varieties are found:

Conchoidal or shelly fracture gives curved faces or waves more or less concentric. It is well known in fiint clays, flints, etc. *Even* fracture has an approximately smooth surface. *Uneven* fracture gives a rough, irregular surface, while the surface of a *hackly* fracture is jagged as shown in metals. A soft pulverulent surface is shown in the *earthy* fracture.

6 POROSITY.

A rock consists of an aggregate of large and small particles cemented together. Between these particles will be many open spaces or pores. The ratio of the volume of these pores to the total volume of the rock represents the porosity of the rock.

According to Van Hise[1] the total pore space in rocks varies from a small fraction of 1 per cent to 50 per cent. In fresh strong granites the amount would be 0.2 to 0.5 per cent and in the very compact limestone 0.55 per cent. In ordinary building limestone it runs from 2.5 to 12.5 per cent. The percentage in sandstones varies from 5 to 28. Van Hise states that many sandstones will hold 10 per cent of water by weight, or have a total pore space of 20 per cent.

The pores in a rock are connected forming winding or irregular channels of greater or less size known as capillary tubes. Their size is determined by the closeness of the mineral particles and the amount of cement filling. These pores or tubes in a quarry rock will contain water, known as the quarry water. A portion of this water is readily evaporated on exposure to the air, while another part is held in the tubes by capillary attraction, and is only removed with difficulty.

The size of the pores does not determine the amount of water absorbed, as a close grained rock with small pores may have a total pore space as large as a coarse grained rock with larger pores. If the pores are saturated with water, serious injury may result on freezing, while if the stone is only partially filled, there will be room for expansion on freezing and little or no injury result. When water changes to ice, it expands 9 per cent and at 30° F., exerts a pressure of 138 tons to the square foot. In a rock this full pressure is not exerted against the rock particles since the spaces are not completely closed resulting in some relief of pressure, but the total pressure is very large.

If the pores form capillary tubes thus firmly retaining

1. U. S. G. S. Mon. XLI.

the moisture, the rock is in greater danger from effects of freezing than one with larger pores from which the water is more readily removed by evaporation. The important factor, as Buckley[2] has pointed out, is therefore size of the pores rather than total amount of pore space.

Another result of the porosity of the stone is the introduction of iron and other staining agents in the water entering the pores, which may change the color. Also this water with its contained air and gases may introduce chemical action, altering the structure or even the strength of the rock.

The percentage of pore space is usually determined as follows: The sample of stone is dried at 100° C and weighed, after immersion in water until pores are filled, the stone is again weighed. The difference in these two weights gives weight of water absorbed which divided by weight of dry stone gives the porosity.

Buckley[3] regards the above determination as giving the ratio of absorption, and would not include the water held in the capillary tubes.

7. NATURE OF THE BOND.

The sedimentary rocks are composed of mineral particles held together by bonding or cementing material. In limestone, the calcite grains are held together by lime carbonate, so the composition of the particles and the bond is similar.

In sandstone the sand grains are held together by one of four kinds of cement: clay, lime, iron, silica. The strength of this rock will depend mainly on the strength of the cement present. The clay cement is the weakest for it readily disintegrates under weathering action permitting the grains to fall apart. Clay cement may also be present in limestone where it tends to break out leaving space for entrance of water and air with their injurious effects on the strength of

2. Bull. Wisc., Geol. Survey No. IV, Building and Ornamental stone, p. 22.

3. *Loc. cit.* p. 69.

the stone. Some sandstones and limestones apparently solid in the quarry are by their content of clay unfit for building stone.

Lime cement in a sandstone is an element of weakness for it is dissolved by action of water though this effect is very slow when the stone is laid in a wall above the water line.

Iron oxides sometimes form the cement in sandstones and the strength of the bond will depend on the nature of the oxide. Ferric oxide is practically insoluble and a very stable compound under ordinary conditions, while the ferrous oxide is more liable to change.

Silica cement in a sandstone forms the strongest bond and such sandstones are very durable. Silica in the limestone brings in an element of weakness.

8. HARDNESS.

Hardness may be defined as the resistance to abrasion or wear. The hardness of a rock depends on the hardness of the minerals composing the rock, the texture, and the character of the cementing material.

Minerals differ from one another in hardness and mineralogists have attempted to make a comparative classification based on hardness. The old scale of hardness was arranged by Mohs as follows:

1.	Talc	6	Orthoclase
2.	Gypsum	7	Quartz
3.	Calcite	8	Topaz
4.	Fluorite	9	Sapphire
5.	Apatite	10	Diamond

A mineral scratched by apatite and not by fluorite would have a hardness between 4 and 5. An ordinary knife blade is about the same hardness as orthoclase. The scale affords a very convenient method of determining the relative hardness of the different minerals. It is far from an accurate

method because the differences between the above numbers are not proportional, for example the difference included between 9 and 10 is greater than between 1 and 9. It is the most convenient method yet devised for comparing the hardness of minerals.

According to this scale the common rock forming minerals have their hardness expressed as follows:

Orthoclase feldspar	6
Plagioclase feldspar	5 to 6½
Mica	2 to 3
Hornblende	5 to 6
Quartz	7
Kaolin	2 to 2½
Calcite	3
Dolomite	3½ to 4
Pyrites	6 to 6½
Iron oxides	5 to 6½

Quartz is the hardest mineral found in the sedimentary rocks, so a quartzitic sandstone of good texture if held together by a good cement, will be the hardest sedimentary rock. The brown sandstone of the southern part of West Virginia is close grained and so hard that it is difficult and expensive to work, while in the Oriskany white sandstone at Berkeley Springs, the sand or quartz grains are so loosely held together that the rock will crumble between the fingers.

Nearly all good building sandstones are softer when quarried than after exposure to the air. Some rocks of this type are easily worked when freshly quarried and after a few months' exposure become so hard that they will turn the edges of tools used in dressing them. The quartz grains certainly do not gain in hardness so the change is due to the alteration in the cementing material or bond. Limestones also vary in hardness. The Martinsburg limestone very close grained and compact is a harder rock than many of the limestones in the western part of the state.

While the hardness of the minerals composing the rock is important in determining the hardness of the rock, the nature of the bond holding the particles together is more important. The strength of this bond as discussed in an-

other section will depend on the size and shape of the grains and also on the chemical nature of the cementing material.

In the United States Bureau of Good Roads, the hardness of rocks is determined by the loss of weight in the abrasion of rock cores, 25 millimeters in diameter. These cores are held endwise against the surface of a steel disc revolving in a horizontal plane at the rate of about 30 revolutions per minute. The specimens are held in suitable clips weighted so as to produce a normal pressure of 1,250 grains between the rock core and grinding disc. Crushed quartz sand between 1 and 2 millimeters in size is fed in the path of specimen to act as an abrasive agent. At the end of 1,000 revolutions of the disc, the sample is taken out and its loss in weight is used in determining the hardness of the specimen by the following formula:

$$H=20-\frac{W}{3}$$

where H is the hardness, and W the loss in grams per 1,000 revolutions.

The following maximum and minimum results of tests made by the Bureau of Good Roads are given for illustration:

No. samples tested.	Kind of rock.	Hardness Max.	Min.
246	Limestone	18.7	0.0
62	Sandstone	19.1	0.0
84	Granite	19.0	13.9

The hardness of stone in its relation to resistance to wear or abrasion is an important quality to be considered in the use for steps, and walks. Soft stone soon wears, becoming uneven and lasts but a short time.

A method of testing the abrasion or per cent. of wear on road materials has been in use in Paris since 1878, and for a number of years in this country. The following description of the method is taken from the Maryland Geological Survey report.

Plate XV.—A.—Marietta Sandstone at the Cleveland Grindstone Quarry, Briscoe, Wood County

Plate XV.—B.—Grindstones cut from Marietta Sandstone at Briscoe Quarry, Wood County.

The Deval machine used for this purpose consists of an iron cylinder 8 inches in diameter and 13½ inches deep, mounted diagonally on a rotating axis. The stone is broken into pieces that will pass through a 2½-inch ring, and 11 pounds of the stone are placed in the cylinder which is firmly closed and rotated at the rate of 30 turns to the minute for five hours, making altogether 10,000 revolutions.

9. SPECIFIC GRAVITY.

The density of a body is measured by its specific gravity, which represents the weight of a substance compared with the weight of an equal volume of water. It is a useful property in comparing relative weights of bodies. Thus a body with specific gravity of 4 weighs twice as much bulk for bulk as one with gravity of 2. A rock with specific gravity of 2 weighs two times as much as an equal bulk of distilled water.

The volume of a solid may be determined by weighing it in the air and then in water, the difference in weight being the weight of the volume of water displaced, which volume is equal to that of the solid. The weight of the substance divided by its volume is the specific gravity of the substance.

The specific gravity of a rock will depend on the minerals composing it, also its compactness in texture and nature and amount of cementing material. The specific gravity of the common rock forming minerals is given as:

Orthoclase feldspar	2.57
Plagioclase feldspar	2.6 to 2.7
Mica	2.7 to 3
Quartz	2.6
Hornblende	2.9 to 3.4
Kaolin	2.6
Calcite	2.7
Dolomite	2.8 to 2.9
Pyrites	4.9 to 5
Iron oxides	3.6 to 5.3

The following table from Merrill[4] gives the specific gravity of a number of building stones:

Granite (Mass.)	2.63
Granite (New York)	2.65
Limestone (New York)	2.69
Dolomite (Illinois)	2.56
Dolomite (Minnesota)	2.59
Sandstone (Colorado)	2.38
Sandstone (Connecticut)	2.36
Sandstone (New York)	2.42
Sandstone (Berea, Ohio)	2.11
Sandstone (Craigleth, Scotland)	2.26

Buckley gives the specific gravity of Wisconsin building stone as follows[5]:

	Maximum.	Minimum.	Average.
Granites	2.713	2.629	2.655
Limestones	2.856	2.740	2.808
Sandstones	2.660	2.524	2.631

In rocks of the same composition, those of highest specific gravity will be most compact, have the greatest weight per cubic foot, and other conditions being equal will be the most durable in use.

10. WEIGHT PER CUBIC FOOT.

In estimating the pressure of large buildings or bridge arches upon their foundations, or in estimating the shipping weight of stone from quarries, it may be necessary to estimate the weight per cubic foot of stone. Since stone freshly quarried varies in its content of moisture, it is impossible to give in a table its true weight.

The only reliable table that can be given is of the weights of dry stone. In estimating a working tonnage of stone per acre it is impossible to give any reliable weight. There is involved in actual quarry operations a loss through spalls, cracks, and minor joint planes. Some quarrymen figure this loss at 10 to 20 per cent. It will vary in differ-

4. Stones for Building and Decoration, p. 406.
5. *Loc. cit.* p. 371.

ent quarries, and also with the methods used in quarrying. Where stone is blasted the loss is usually greater than where the stone is quarried by various methods without the use of powder. In limestone especially and also in sandstone, cavities are often present or clay seams cut into the rock so that the formation is not a solid block of stone. For these reasons estimates of total quantity of stone available in a given area can only be approximate, and estimates made by different engineers on the same tract will vary.

The weight of the dry stone can be calculated and the tonnage computed on that basis, but this will not be the actual working tonnage. Merrill gives the following dry weights per cubic foot for a number of building stones:

Granite (Mass.)	165	pounds
Granite (New York)	165.4	"
Limestone (Indiana)	168	"
Limestone (Bedford, Ind. oolite)	174	"
Limestone (New York)	168.2	"
Dolomite (Illinois)	160	"
Dolomite (Minn.)	162.2	"
Sandstone (Colo.)	168.4	"
Sandstone (Conn.)	148.5	"
Sandstone (New York)	151.2	"
Sandstone (Berea, Ohio)	131.9	"

Buckley found the weight of the Wisconsin limestones ranged from 153.69 to 176.6 pounds, with the majority ranging from 165 to 175 pounds to the cubic foot. The sandstones varied from 115.55 to 148.3 pounds per cubic foot.

The weight per cubic foot of a given stone is readily calculated from its specific gravity. The weight of a cubic foot of water is 62.3 pounds, which multiplied by the specific gravity will give the weight of the stone per cubic foot. A stone with specific gravity of 2.5 would weigh per cubic foot, 62.3x2.5 or 155.75 pounds.

According to Buckley[6] this estimate gives the weight of a cubic foot of stone of the given specific gravity without pore spaces. In order to obtain the actual weight, he deducted from this estimate, the weight of a quantity of stone

6. *Loc. cit.* p. 69.

of the same specific gravity equal in volume to the percentage of pore space in the stone. This gives the actual weight of the stone free from interstitial water.

11. ELASTICITY.

Elasticity is the tendency of a body after change in shape or volume to return to its original form after removal of the deforming force. This property is further discussed in chapter on testing of stone.

12. DURABILITY.

The value of building stone depends not only on its strength but also on its ability to withstand disintegration and decomposition, or in other words on its durability. Disintegration is a mechanical change causing the stone to crumble, while decomposition is a chemical action causing a stone wholly or in part to dissolve, or alter into other compounds.

Some building stone apparently sound and durable at the quarry after a few years exposure in a building is seen to be soft and crumbling. In many of our cities it is not difficult to find such examples of disintegrating walls. Practically all stone in the ground under the action of the aqueous and atmospheric agents crumbles to soil. A good building stone, however, when removed from the ground and placed in a building will be durable for long periods of time.

The various agents causing these changes are classified by Buckley[7] as follows:

I. Agents of Mechanical Disintegration.

A. Temperature Changes.

1. Unequal expansion and contraction of the rock or its mineral constituents.
2. Expansion and contraction of the included water, occasioned by freezing and thawing.

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7. *Loc. cit.* p. 17.

B. Mechanical Abrasion.

1 Water
2 Wind
3 Feet

C. Growing Organisms.

D. Man's Ignorance and Incautious Methods of Working and Handling Stone.

II. Agents of Chemical Decomposition.

A. Water—solvent action.
B. Carbon dioxide.
C. Sulphurous acids.
D. Organic acids.

I. Temperature Changes.

With but few exceptions, heat expands and cold contracts substances. Rocks are subject to this expansion and contraction but their rate of heat conductivity being low, the changes are usually confined to the surface portion.

Rocks are seldom composed of a single mineral, but made up of several minerals which have different degrees of expansion and contraction. On account of these differences the minerals expanding under heat will exert unequal pressure, crowding one another. On cooling, there will be a tendency to pull apart one rock component from another, so that unequal stresses are introduced. Repetition of these movements will have a tendency to weaken the rock. The daily and seasonal changes of temperature will produce these effects on the surface of the exposed rock, resulting in time in the spalling or breaking off of layers. The effects will be the greatest where the greatest variations in temperature are found. On deserts or semi-arid plains, the difference between day and night temperatures is as great as 100° and exceptionally 150° F.

Livingston the great explorer of Africa describes the effects of such temperature changes on rocks as follows[8]:

"Several of the mountain sides in this country (Gova) are remarkably steep, and the loose blocks on them sharp and angular, without a trace of weathering. For a time we considered the angularity of the loose fragments as evidence that the continent was of comparatively recent formation; but we afterwards saw the operation actually going on, by which the boulders are split into these sharp fragments. The rocks are heated by the torrid sun during the day to such an extent that the thermometer placed on them rises to 137° in the sun. These heated surfaces cooling from without in the evening air, contract more externally than within, and the unyielding interior forces off the outer parts to a distance of 1 to 2 feet. Let anyone in a rocky place observe the fragments that have thus been shot off, and he will find in the vicinity pieces from a few ounces to 100 or 200 pounds weight, which exactly fit the new surface of the original block; and he may hear in the evenings among the hills, where sound travels readily, the ringing echo of the report, which the natives ascribe to the Mebesi or evil spirits, and the more enlightened to these natural causes."

Merrill and other American scientists have described similar effects in the western part of the United States.

In this latitude the daily range of temperature is much less, but the seasonal variation is large, and there is often an extreme variation in a very short time.

There are some very complete records of temperature covering a period of 30 years preserved in the northern Pan Handle area of West Virginia. From a study of these records, the following ranges of temperature are found:

An average yearly range of 46° F; an extreme annual range of 120°, a daily range of 53° in January and 30 in July.

The effect of change of temperature on the expansion of rock slabs was measured by Colonel Totten in 1830-1833. He determined the expansion to be,

8. Livingston's Zambesi, p. 492, quoted Jukes Brown Phys. Geol., p. 100.

9. Quoted by Dana, Manual of Geol., p. 259.

One inch of granite expands	0.000,004,825	inches	each	degree	F.
One inch of limestone expands	0.000,005,668	"	"	"	"
One in. of red sandstone exp's	0.000,009,632	"	"	"	"

The extreme annual range of 120° F. temperature in this state would cause a surface of limestone 10 feet long to expand 8-100 of an inch.

With these changes of temperature there is also present the destructive effects due to freezing and thawing of included moisture. All rocks contain moisture. The amount of water in different rocks is shown in the following table from Dana's Geology (p. 205):

Porphyry	0.012	per cent of the rock mass.
Coarse granite	0.37	" " " " " "
Sandstone	2.73	" " " " " "
Slate	0.19	" " " " " "
Limestone	3.11	" " " " " "

The amount of moisture absorbed by rocks after drying to 150° to 200° F. was found to be.

Potsdam sandstone	2.26 to 2.71	per cent.
Trenton limestone	0.32 to 1.70	" "
Dolomites	1.89 to 13.55	" "
Medina sandstone	8.37 to 10.06	" "

Water in freezing exerts a confined pressure of 138 tons to the square foot, therefore the destructive effects of freezing in a saturated rock must be serious in estimating the durability of the rock. As discussed under the head of porosity, the damage will be greater in compact rocks wth small pores forming capillary tubes than in a porous rock where the openings are larger.

The structure of the rock will also have an important bearing on the effects of freezing. Laminated rock, fissile rock will permit the inflow of water along these planes and the expansion through freezing will tend to separate the rock along these planes. In the walls of a building above water line, the rock will not be usually saturated with water so that the destructive effects will be much less than in the exposed portion of a quarry. As outlined by Buckley[10] the

10. Missouri Geol. Survey, 2nd series, Vol. 4, p. 22.

amount of water in the rock at a given time will depend, (1) upon the amount of water initially absorbed; (2) the time that has elapsed since the water was absorbed; (3) the size of the pores; (4) the positon of the stone; (5) the condition of the atmosphere.

If the pores are only partially filled with water, there will be less danger than if saturated. If the water has room in the pores to expand and just fill them, no danger will result. If the pores are large, the water will escape more readily by evaporation, or in freezing there will be room for the expansion to the outside. Stone laid below the water line will contain more water than stone in the wall above this line. Stone with lamination or sedimentary planes laid on edge will be in more danger of breaking than if laid on the bed. If the atmosphere is dry evaporation from the stone will be more rapid. If the atmosphere is saturated or nearly so there will be very slow evaporation from the stone. Buckley has emphasized in his report the fact that in considering danger of disintegration of stone by freezing and thawing, the size of the pores is of greater importance than total amount of pore space or total amount of absorption.

I-B. Mechanical Abrasion.

The breaking down of rocks by mechanical agencies is one of the common changes in nature. Rain and running water are wearing away rocks along the hillsides and in the valleys, ravines, canyons, buttes, etc., all furnish testimony of the wonderful work accomplished by running water. Along the sandy coasts of oceans and lakes and on the western plains wind driven sand carves its characteristic sculpture.

While these agencies of rain and wind have a similar effect on stone structures, it is only exceptionally important. Under average conditions the effect is scarcely noticeable in a building.

The abrasion of stone in steps and walks by feet is often noticeable. Some soft sandstone is thus worn into hollows,

and even the harder sandstone is affected in time. Some of the flagstone pavements in this state show the low resistance to such abrasion. It therefore becomes important to determine the abrasive resistance of stone for these uses

I-C. Growing Organisms.

Roots and rootlets of trees penetrating the crevices of rock in the ground, by their growth expand these openings breaking the rock apart. The decaying vegetation furnishes organic acids that are agents of decomposition, making the water a solvent for the rock constituents which are thus removed.

Algae and lichens growing over the surface of the rock protect it in part from destructive atmospheric agencies, but in decay furnish the acid solvent, so that they are both preservative and destructive in action. The green algae growth on north side of stone walls discolors the stone forming an objectionable feature in the appearance of the stone.

I-D. Careless Methods of Working and Handling the Stone.

A quarry of excellent quality of building stone may furnish very poor stone by carelessness in quarrying. In some quarries an effort is made to secure a large mass of stone with least possible work. Holes are drilled and heavy charges of dynamite are used, resulting in a large blast throwing out a mass of broken stone from which blocks are taken for building purposes. By this wasteful method a large portion of the stone is ruined, the quarry face is badly shattered. The blocks selected for building purposes are very liable to have incipient fractures in them which form planes of weakness to be enlarged later by the various destructive effects above described.

There is one good sandstone quarry in this State studied in the course of this investigation where the entire face is crossed by irregular fracture planes due to heavy blasting. If this quarry is properly worked there will be a large waste of stone before this zone of fracture is passed.

Where a quarry is rented from the owner for one season to be used the next by another party, the object of the first worker is often to secure a larger yardage with as little labor of drilling and cutting as possible. From the mass of stone thus thrown out by a few heavy blasts enough stone of proper size may be obtained, leaving the waste rock to encumber future work.

The quarry owner should see that his stone is economically worked and avoid waste of good stone as far as possible. For the best results experienced quarrymen should only be permitted to open the quarry. Careless work will not only involve waste of stone, but the damaged blocks later disintegrating in a building will injure seriously the reputation of that particular stone.

As one visits the various quarries of the state he will see a great difference in methods of working. At Rowlesburg the gray or blue sandstone is separated by light charges of powder from the main joint planes. It is then broken into blocks of required size by drilling a series of holes along the line of desired fracture which is then gently forced apart by plugs and feathers. The stone is thus broken smoothly and with no shattering. The waste in this quarry is at a minimum.

Fine grained sandstone, limestone, and marble, are cut out in other states in large blocks by use of channelling machines. The joint planes should be used as planes of fracture as far as possible and the blocks removed by a series of light charges of powder.

Usually stone works easier under tools when first quarried than after seasoning. In such stone it would be better to dress and shape the stone as it comes from the quarry as there would be less danger of breaking the texture of the main mass and introducing lines or planes of weakness. The method of dressing the stone may have an effect on its durability. Sawed stone is apt to be less injured than hammered stone. Smooth faced stone will give less chance for absorption of water and the lodgment of carbon, dust, etc., from the atmosphere.

II. Agents of Chemical Decomposition.

The chemical decomposition of stone in a building is comparatively slight. Water with its contained gases and salts may cause some alteration especially in limestones. Carbonic acid gas in water has a solvent action on limestone which is probably very small in the wall. In cities the large quantity of smoke thrown into the atmosphere, will furnish sulphurous acids and carbon dioxide which may form magnesium sulphate from the carbonate in the limestone or dolomite. When this comes to the surface it may leave a white coating, or as it is usually termed white-wash, injuring the appearance of the building.

Organic acids from decaying algae, vines, etc., have usually very little effect on the strength of stone though by lodgment of dirt in them, discolorations may appear.

13. WORKABILITY.

The ease with which a stone may be quarried depends to a large extent on the presence of stratification and joint planes. The ease of working the stone into blocks of desired size and shape with chisel, depends mainly on the hardness and texture

Some stone works readily in all directions and is called a free stone. It can be carved in most delicate patterns. Other stone can be worked readily in certain directions and not in other planes. Still other stone is hard and brittle, breaking easily under blows of a hammer into fragments so that it is almost impossible to work in desired form. Some stone is so hard that it will turn the edges of tools and is thereby too expensive for economical use. The strength of the dressed stone and its cost will depend on its workability.

14. AVAILABILITY.

The amount of cover or stripping to uncover the quarry stone is an important factor in operation. A very heavy

rock cover may prevent the use of a stone, otherwise very desirable. The amount of this cover which will be prohibitive to quarry working will depend on the quality of the stone, the demand, cost of stone from other quarries in competition. There are quarries in operation in this state where 50 to 60 feet of cover must be removed. There are quarries now idle where the cover is only a few feet.

The quarries must be located near transportation lines and not too far distant from market. The distance a stone can be shipped will depend on its quality and reputation. The Bedford, Indiana, oolitic limestone is an easy working stone of pleasing color, and durable. It is so well known in the stone trade that it is shipped to all parts of the country. There is stone in West Virginia quarries that if properly advertised would reach a large eastern market but today is not even worked for local use.

West Virginia is connected by rail and water with large markets over short distances, thus affording low cost of transportation for its various products. The northern part of the state is 90 miles from Pittsburg by water and rail; Harpers Ferry, at the eastern side, is 56 miles from Washington by rail, 81 miles from Baltimore, 175 miles from Philadelphia, 273 miles from New York; Hinton on New River is 396 miles from Norfolk, and 311 miles from Richmond by rail. In all these cities there is a large demand for building stone supplied from various sources. A small amount of the supply comes from West Virginia. There is no reason why more of the stone used in these cities should not be taken from the quarries of this state.

TRANSPORTATION LINES.

The following description of transportation lines in West Virginia was given by the writer in connection with the discussion of clays and cements in volume III of the reports of this survey.

The waterways of the state afford 600 miles of navigable water, improved by the national government. Up and down

these streams ply the packets and barges bringing in supplies and taking out to the marts of the world the natural products of a prosperous State, wealthy in nature's endowments, buried in the earth and growing above in a free air.

Four thousand miles of railroads penetrate its hills and cross its valleys. The state is crossed by three trunk lines. The Baltimore and Ohio at the north connecting at the east with Washington, Baltimore, Philadelphia, and New York, and at these points with steamers to all parts of the world; and at the west with Chicago and St. Louis, the gateways of the great West. The branches of this great and oldest system stretch out like fingers in all directions to collect and remove the products of soil and mine.

At the south are the Chesapeake & Ohio, Norfolk & Western and Virginia railroads, connecting the State with the various cities in Ohio and Kentucky, while eastward they reach the coast and cities enroute.

The Western Maryland through its connections at Elkins links the central portion of the state to tide water at Baltimore.

In addition to these trunk lines are the valuable local lines of the Coal & Coke, Kanawha and Michigan, Little Kanawha, Coal & Iron, Dry Fork, Morgantown & Kingwood, and other lines, built into almost inaccessible places, there to develop a dormant wealth of natural resources. New lines are building and others as yet on paper will be constructed, bringing wealth and comfort to mountain recesses.

CHAPTER XX.

THE SANDSTONES OF THE DUNKARD OR PERMO-CARBONIFEROUS SERIES.

Gilmore sandstone.
Nineveh sandstone.
Fish Creek sandstone.
Dunkard sandstone.
Marietta sandstone.
Mannington sandstone.
Waynesburg sandstone.

The limestones of West Virginia were described in Volume III of the State Geological Survey, and the present report is devoted to the sandstones. This state is well supplied with sandstones which are found in nearly all portions of the commonwealth, but which vary in thickness, quality, and value as building stone. Most of the stone quarried for buildings and other structures in this state is sandstone.

In 1907 according to the statistics of the U. S. Geological Survey, the total value of limestone quarried in West Virginia was $855.941, of which value $528,587 is represented by crushed limestone for furnace flux and the value of the stone quarried for structural use was only $420. The sandstone industry in 1907 in the state had a value of nearly $197,926, classified by uses as follows according to the U. S. Geological Survey report on Mineral Resources for 1907:

Rough building stone	$ 46,263
Dressed building stone	59,609
Paving	3,085
Curbing	12,038
Rubble	42,021
Riprap	4,901
Road making	240
Railroad ballast	1,220
Concrete	27,845
Other uses	704
Total	$197,926

The following table from same source gives the value of total production of sandstone in the state for the past 17 years.

1907	$197,926
1906	113,369
1905	171,309
1904	287,381
1903	252,204
1902	423,532
1901	103,010
1900	72,438
1899	33,860
1898	14,381
1897	47,288
1896	24,693
1895	40,000
1894	63,865
1893	46,135
1892	85,000
1891	90,000
1890	140,687

It is thus seen that while the limestone industry is far more important in value of output than the sandstone, the sandstone is the more important building stone industry. There are very few limestone building stone quarries in the state, and about 60 sandstone quarries.

The data on sandstone quarries has been collected during the field season of 1907 for this report, and is given in the following pages together with a summary of the general descriptions of the sandstone strata given by Dr. I. C. White in the coal report of the Survey, Volume II. The different sandstones and their quarry development are arranged in this report in their descending geological order. The present chapter includes the discussion of the sandstones of the highest strata exposed in this state, the Dunkard series.

GILMORE SANDSTONE.

The Gilmore sandstone was named by Dr. J. J. Stevenson from a township in Greene County, Pennsylvania, where it forms long lines of cliffs near the summits of the hills. According to Dr. I. C. White, it is a massive bed of coarse yellowish brown sandstone, 25 to 30 feet thick. "This sandstone has been one of the principal agencies in preserving the higher portions of the Dunkard Series from erosion, and holding up the ridge lands into broad arable fields favorably located for agriculture. The stratum is very frequently not exposed in cliffs but simply makes a well defined bench in the topography.[1]"

NINEVEH SANDSTONE.

This sandstone is found above the Nineveh coal about 200 feet below the Gilmore sandstone and is desiribed as follows, by Dr. I. C. White (Vo. II, p. 108):

"This like the Gilmore above, often gives rise to cliffs, especially in Marshall, Wetzel, western Monongalia, Marion, Harrison, and Doddridge. The rock is yellowish gray in color, and has frequently been quarried for building stone, though at times its texture is not firm enough to prevent crumbling when exposed to frost, etc. An attempt was made to quarry it near the eastern portal of the Short Line (B. & O.) Railroad tunnel in western Harrison, but the sand grains are so loosely cemented that the rock crumbles too easily for building into exposed structures. It appears to be this stratum that crops out in bold cliffs along the B. & O. railroad between Salem and Long Run in Doddridge county, and also at Littleton in Wetzel county, half way up the hills. The same sandstone has been quarried on the land of Thomas White, one mile below Maple, Monongalia County."

1. W. Va. Geol. Survey, Vol. II, p. 107.

FISH CREEK SANDSTONE.

Dr. White describes this sandstone as follows (Vol. II, p. 110): "At 135 to 150 feet below the Nineveh Coal there occurs another sandstone horizon known as the Fish Creek sandstone of Stevenson. It makes great cliffs along the stream of that name in Marshall county, and also along the B. & O. railroad between Littleton and Burton, Wetzel county, where it has been extensively quarried for building stone, of which it produces a very fair quality.

"This stratum, like the Nineveh and Gilmore sandstones above, makes a distinct terrace in the topography, so that its presence can be easily detected, even when it does not stand out as a bold cliff."

Littleton Stone Company at Littleton, Wetzel County.

Littleton is located in Wetzel county on the main line of the Baltimore and Ohio railroad, 42 miles east of Wheeling. B. F. Connelly has opened a quarry about one mile east of town near the top of the high hill. The stone is carried down an incline to a small railroad which connects with the B. & O. road. The stone was first opened about 1899, and the present quarry has been in operation three years. Ten to twenty-five men are employed and three car loads of stone shipped daily during the working season. The stone has been used in various cities east and west along the B. & O. railroad, and a large quantity has been used in the railroad construction. The stone for the annex to the Moundsville penitentiary came from this quarry.

Quarry. An oil well drilled on top of this sandstone reached the Pittsburg coal at 810 feet. This interval would place the stone about the horizon of the Fish Creek sandstone of Stevenson.

The quarry face runs N. 30° W. and is 400 feet long and worked back 60 feet in the present quarry. The outcrop shows nearly a mile of stone around the hill.

The section of the quarry is as follows:

	Feet.
Shales and soil cover	10
Shaly sandstone	6
Main sandstone ledge (brown in color)	28
Blue flaggy sandstone	20

The sandstone, blue and brown in color, continues 30 to 50 feet below the bottom of the working quarry. The joint planes run N. 30° W. and N. 50° E. Physical tests on this stone are given in chapter XXVI of this report.

DUNKARD SANDSTONE.

At a number of places in the interval between the Dunkard and Jollytown coals, a sandstone is found and has been named the Dunkard. This stone has been quarried at one locality in the state, but in 1908 this quarry was abandoned and the railroad switch removed.

Batson and Company Quarry at Hundred, Wetzel County.

The town of Hundred is four miles east of Littleton on the Baltimore and Ohio railroad. Batson and Company of Moundsville in 1904 opened a sandstone quarry one mile west of Hundred or 15 miles west of Mannington. The stone was used by the B. & O. for bridge piers and was shipped to various cities for building stone.

Quarry. The Jollytown coal outcrops a few feet above the creek level at this place and just below the sandstone, which would make the horizon the Dunkard Sandstone.

The face of the quarry runs east and west 200 feet long and worked back 40 feet. The stone is blue and buff in color. The blue stone is fine grained, strongly laminated with some white but more black mica flakes. The brown stone is made up of small quartz grains loosely cemented and rather porous, with few scattered white mica scales and some white kaolin particles.

The bottom of the quarry is 18 feet above the creek level and a section shows,

	Feet.
Buff shales	20
Shaly sandstone	3
Sandstone, blue and buff	25

There are no well defined joint planes. A photograph of this quarry is given in plate XIII.

Microscopical Structure. A thin section of the Hundred quarry sandstone was examined under the microscope by Mr S. L. Powell of Johns Hopkins University, who reports as follows: "The original material of this rock was a mixture in about equal proportions of grains of quartz, feldspar, kaolin, mica (biotite), together with more or less argillaceous matter. These minerals except the quartz, have undergone extensive alteration. The feldspars may be seen in every stage of decomposition. A few of them are fresh enough to show twinning lamellae, others are changed to kaolin, and yet others entirely changed to a fine mosaic of alteration products chiefly muscovite, chlorite, and kaolin. But little of the original mica remains, the change having been chiefly to iron oxide which is abundant.

"The quartz grains vary from rounded to more or less angular forms, and in many instances are cemented by silica into compact areas. Around such areas and individual grains as well, there is a coating of iron oxide with kaolin which frequently fills the interspaces between the grains. The matrix is partly silica, partly oxide of iron and kaolin with a considerable amount of argillaceous material. The grains would average about 0.45 millimeter in diameter."

The physical tests on this sandstone are given in chapter XXVI.

MARIETTA SANDSTONES.

Dr. I. C. White in Volume II (p. 112) of the Survey reports describes these sandstones as follows:

"The interval of rocks 200 feet or more in thickness which separate the Jollytown coal from the Washington

coal is often largely occupied by an immense sandstone deposit 100 or more feet in thickness, and in two or three great ledges separated by shales. The writer has termed the sandstone horizon the Marietta sandstones from their occurrence near that city on the Ohio river where they have long been quarried for grindstones, of which they make an excellent quality. The color of the rock is generally of a yellowish brown and they often form immense cliffs as at Raven Rock, on the Ohio River.

"In Roane, Jackson, Mason, Calhoun, Gilmer, Wirt, Lewis and Ritchie counties especially, there are many localities where the Marietta sandstones form long lines of cliffs on the summits of the ridges, and often weather into fantastic shapes which from a distance resemble a closely crowded group of immense haystacks. One of these localities in Roane on the lands of Mr. Munson Jackson has given rise to the term "Jackson Rocks", under which name this outcrop is locally known over a considerable region. These sandstones, though frequently coarse in grain, rarely hold pebbles of considerable size, only one such locality (along the Parkersburg and Staunton turnpike near the line between Gilmer and Ritchie counties) being known to the writer. Occasionally the shales which usually separate this sandy horizon into two or three separate strata, thin away as at Rock Lick, Marshall County, and then we get a solid mass of sandstone 100 feet thick.

"This horizon has recently been quarried for grindstones to a considerable extent between Parkersburg and Letart along the Ohio river, and it is quite probable that in many other regions a valuable grindstone grit could be found at this geological level."

These sandstones have been quarried for many years in the vicinity of Parkersburg. At the present time the grindstone quarries have been practically abandoned, and the building stone quarries are not as extensive as in the past.

Plate XVI.--Naughton Quarry in Waynesburg Sandstone at Cornwallis, Ritchie County.

Safreed and Debussey Quarry at Sherman, Jackson County.

Sherman is a small town located on the Ohio river division of the Baltimore and Ohio railroad, three miles and a half north of Ravenswood and 31 miles south of Parkersburg. Three or four quarries have been opened near this place but only one was in operation in 1907. They were opened as grindstone quarries, but in recent years, the stone has been quarried on a small scale for building stone mostly for local use or shipped to Ravenswood.

W. H. Safreed and Debussey have taken out stone from a quarry just south of the railroad station and 100 feet above the railroad track level. The stone belongs at the horizon of the Marietta Sandstone.

Quarry. The face of the Safreed quarry runs north and south. The rock is light gray in color composed of rounded grains of quartz and scattered flakes of black and white mica. Some of the layers break along parallel lines and have a banded or foliated appearance. Some of the joint planes show very smooth surfaces, almost slickenslides, and some iron spots occur in the stone.

In places the rock has slipped down the hill in form of large boulders which also have been quarried. A section of the quarry shows:

	Feet.
Broken rock and soil	15
Light gray sandstone	12
Irregular honeycomb sandstone	4
Greenish gray sandstone	6

The joint planes run N. 60° W. and N. 20° W.

Lone Cedar Grindstone Company Quarry at Lone Cedar, Jackson County.

At Lone Cedar, 10 miles north of the Sherman quarry and 21 miles south of Parkersburg on the Ohio river bluff and near the B. & O. railroad, a grindstone quarry has been operated on a small scale since 1897 by the Lone Cedar Grindstone Co., of Parkersburg. The floor of the quarry is 200 feet above the B. & O. track.

Nine men were employed and as high as $800 worth of stone has been quarried in one month, but the industry has declined in the last two years and the quarry is now about closed. The stone is cut out square, then hand dressed into a round shape, and finally turned to proper size and shape. The common sizes of grindstones made at this quarry are four feet in diameter with 18 inch face, which sell at $11 each, and seven foot in diameter with 18 inch face. The stone is claimed to have an excellent grit and to have proved very satisfactory on the market.

Quarry. The face of the quarry runs north and south following the direction of the river bluff, and it is worked to the east. The upper ledge used as building stone is finely foliated, the planes marked by an abundance of black and white mica flakes, and the stone is fine grained. The lower or grindstone ledge is made up of small rounded quartz grains, and the fresh stone pulverizes easily. It seems to be loosely cemented yet forms a fairly solid rock, and contains white and black mica flakes. It weathers to a light yellow brown color especially near the joint planes.

A section of the quarry shows:

	Feet.
Dirt or clay cover	6
Red shales	30
Blue hard sandstone	12
Grindstone ledge	14
Blue shales.	

The working of the grindstone ledge thus requires 48 to 50 feet of stripping and has proved too expensive for profitable working. The 12 foot ledge would make a good building stone with a good blue color and the shales are adapted to brick manufacture. A combination of these different industries would make the stripping profitable.

The joints in this quarry run N. 70° W. and N. 20° W.

Dunlap Quarry at Parkersburg, Wood County.

The Dunlap quarry is located one mile and a half south of the city of Parkersburg and has been opened for 20 years or more. The stone was hauled in wagons to the city

where it was used for foundations, and also for curbing. For the latter use it has not proved satisfactory as it tends to split or scale off at the edges.

The upper ledge has a bluish gray color and is very close grained. White and black mica flakes give it a finely speckled appearance. The buff or brown sandstone shows a tendency to foliation and breaks readily parallel to the bed. Its upper portion is full of mica.

Quarry. The face of the quarry runs east and west 350 to 400 feet, and it is worked to the north with present width of 50 to 60 feet. At the south end of the quarry the outcrop is weathered to a loose sand with three feet of flaggy stone at the top covered by three feet of soil and stone. The main portion of the quarry has the following section exposed:

	Feet.
Soil	3
Buff shales	12
Chocolate brown shales	6 to 8
Blue sandstone	3
Brown sandstone (full of mica)	1
Brown sandstone (worked)	30

The joint planes run N 20° E and N 20° W.

John Doyle Quarry Near Parkersburg.

The John Doyle sandstone quarry is located out Lubeck avenue, a short distance from the Dunlap quarry and one mile and a fourth from center of city. The floor of the quarry is 70 feet above the Little Kanawha river. The sandstone is full of mica giving it a silvery appearance and it varies in color from a light blue to gray. It makes a very pleasing trimming stone in its color and is readily split into shape.

Quarry. The face of the quarry runs east and west 150 feet long, and the stone has been worked back 60 to 80 feet. A section of the quarry shows.

	Feet.
Shaly sandstone	2
Red and buff shales	8
Light gray sandstone	5
Light gray sandstone	5
Blue to gray sandstone	12

The joint planes run N 80° W and N 10° E.

John Hettick Quarry near Parkersburg.

Mr. John Hettick worked for some years a sandstone quarry two miles east of Parkersburg at the side of the county road across the bridge over Worthington Creek near the Roofing Tile plant. The stone was blue to gray in color, weathering brown and foliated with parallel planes marked by mica flakes.

Quarry. This was a small quarry with one derrick worked from time to time as there was a demand for the stone. It was finally abandoned in 1906 and is now filled with water. The top of the sandstone is about 60 feet below the bottom of the Keenan quarry in the city. A section of the quarry made three years ago shows:

	Feet.
Yellow clay	4
Sandy shales	2
Sandstone	3
Sandstone	10

C. D. Merrick Quarry Near Parkersburg.

On the C. D. Merrick farm, one-fourth mile back of Tavnersville, which is two miles up the Little Kanawha river from Parkersburg, a quarry was opened by Mr. J. P. Whealden. The stone like in the preceding Parkersburg quarries is at the horizon of the Marietta Sandstone. The sandstone is blue to gray and buff in color, and these colors appear to be durable upon exposure. The rock is composed of rounded quartz grains somewhat loosely cemented, and shows a considerable quantity of white mica flakes and some black mica. Some of the ledges are laminated, and in a few places the rock texture is quite open. The buff stone is composed of small, rounded, clear, quartz grains, in a brown ground mass. The stone splits readily into building stone blocks, caps and sills, also curbing. It is hauled in wagons to the city where it finds good sale.

Quarry. The face of the quarry runs north and south

about 80 feet long and it is worked to the east 25 to 30 feet. A section of the quarry shows:

	Feet.
Broken rock cover	3
Flaggy buff stone	6
Brown or buff sandstone	7
Blue sandstone	6

As the stone is followed back into the hill, the cover will increase to 12 or 15 feet. In some parts of the quarry the lower blue sandstone increases to 12 feet and the overlying buff stone is reduced.

The joint planes run N. 10° W. and N. 45° W. The physical tests on this stone are given in Chapter XXVI.

Samuel Keenan Quarry, Parkersburg.

A sandstone quarry in the city of Parkersburg on East Seventh street has been worked for 40 years, and has been operated nearly half this time by Mr. Samuel Keenan. The bottom of the quarry is 90 feet above the Washington coal at mouth of Little Kanawha river, and the stone is one of the ledges of the Marietta sandstones.

The sandstone has a blue to greenish-blue color, glistening with mica flakes, and is more or less banded with planes formed of black mica. The color as shown in exposed stone in the quarry and in buildings is very durable, though in the old portions of the quarry the face shows a rusty brown color where water from the overlying red shales has stained it.

The stone is used for caps and sills, foundation stone, and blocks of large size can be obtained. It has been used in a number of the older buildings of the city, where it still keeps its blue color with little change and is a very durable stone. The first story of the High School building was constructed in 1891 of this stone (See plate XIV).

Quarry. The quarry face runs east and west for 230 feet. It is worked to the north and the face is now back 100 feet from its original outcrop. The quarry is mostly

worked out to the lot lines so that work has about ceased. The main quarry shows the following ledges:

	Feet.
Loam and clay cover	10
Red shales	1
Brown sandy shales	10
Blue sandstone	30
Banded blue sandstone	10
Red to brown shales (in brewery well)	30

The lower courses in the quarry show cross bedding. The 30 foot ledge breaks into layers four to five feet thick which show more or less banding. At the east end of the quarry the stone is exposed as follows:

	Feet.
Shales and soil	10
Sandstone	4
Shales	1½
Sandstone	4

The cover of loam is a very sandy clay which breaks with prismatic cleavage much like the western loess deposit, and is a river clay.

Cleveland Stone Company Quarry Near Parkersburg.

The Marietta sandstone is especially valuable for grindstones, and received its name from the grindstone quarries near Marietta. It is the second important grindstone horizon in this country being only surpassed in quantity of output by the Berea quarries near Cleveland. The Marietta stone is claimed to have a better grit than the Cleveland stone, but it is not so free working. The industry has been a most prosperous one on the Ohio side, but on the West Virginia side while the stone is of similar quality and well located for working and for transportation, it has been the policy of the company to reduce the output until it has almost ceased. The Cleveland Stone Company secures most of their present supply from Berea, but it is hoped they will renew their operations in West Virginia in the near future.

This company controls two quarries seven miles north of Parkersburg. The old Quarry is in the Ohio river bluff

near the Baltimore and Ohio railroad at a station named Briscoe. The track at this place is 20 to 25 feet above the river, and the sandstone comes down to the track level, though the floor of the quarry is 35 to 40 feet higher. There is a long line of these old quarries which have been abandoned four or five years, and a new quarry was opened about a mile and a half south and a mile back from the railroad at a point named Boaz. This quarry was worked three to four years and abandoned in 1906 at least temporarily so that at present time no work is done in this section except in the working up of accumulated stock.

Quarry. The quarry face in the old quarry on the river bluff is nearly 600 feet east and west, but openings in this ledge have been made down as far as the county road, a distance of about one mile.

A short distance from the grindstone quarry is an old building stone quarry where the rock is tilted at an angle of about 20 degrees to the south. The blocks are quarried two feet thick, and are much foliated parallel to the inclined bedding. The stone splits readily along these planes which are marked by an abundance of white mica flakes. The rock a short distance east is horizontal. Below the stone is a mass of shales, and the quarry is located in a small ravine. The tilted character is probably due to a slipping of the sandstone on the shales below.

The sandstone in these quarries has a brown and blue color and contains much mica. A section of the old grindstone quarry shows:

	Feet.
Reddish shales	10
Coarse brown sandstone	12
Compact blue sandstone	4
Fine grain brown sandstone	4

Both the blue and the brown sandstones were used for grindstones.

In the new quarry at Boaz, illustrated in plate XV, the stone is mostly blue, but near the outer portion of the quarry is brown. It has been worked in a trench 850 feet long and 35 feet wide. The face is worked along a north and south

line. Toward the south the stone has less cover and is brown in color and softer. The bottom ledge is coarser in grain than the upper and has small flint particles in it, so that it is not used for grindstones.

As the stone is followed to the west, the cover increases and would require expensive stripping. A section of the new grindstone quarry at Boaz shows:

	Feet.
Clay and shale cover	3
Shaly sandstone	4
Blue sandstone (used)	10
Blue sandstone (not used)	5

While some of this stone has been quarried for building stone, the main use was for grindstones. The stone is cut out of its ledge in a circular form and then hauled to the mill at the old quarry on the river where it is turned smooth and cut into proper form and size. These grindstones are made 6 feet and less in diameter with a 10 to 24 inch face, and a five inch square opening at the center to fit on a shaft. The six foot stone usually has a ten inch face and weighs about 4,000 pounds. A four foot stone with 27 inch face, in the rough will weigh about 10,000 and when trimmed into shape will weigh 8,472 pounds. In 1906, twelve men were employed and the average output was three to four complete grindstones a day.

Chemical Composition. A sample of stone from the new quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica	89.73
Alumina	4.67
Iron	1.93
Lime oxide	0.12
Magnesium oxide	0.43
Alkalies	1.58
Loss, etc	1.54

Microscopical Structure. Mr. S. L. Powell of Johns Hopkins University examined a thin section of the Briscoe sand stone and reports as follows: "This rock was originally a

sand composed essentially of grains of quartz, feldspar, kaolin, and a little mica (biotite). Quartz is the predominant mineral in the rock. The quartz grains vary greatly in outline, some are well rounded, others elongated and water worn, and yet others have jagged, sharp angular borders. Generally the grains of quartz have been slightly enlarged by secondary silica; and when in contact, silica forms the cement for the grains which in certain areas of the section are fairly well cemented, in others they are not.

"Feldspar is abundant, both orthoclase and plagioclase, and in all stages of preservation from a few fresh ones showing beautiful twinning striations to those completely altered. The abundance of feldspars and probably other original ferro-magnesian constituents have given rise to a considerable development of secondary minerals; such as calcite, chlorite, muscovite, oxide of iron, and kaolin. These minerals have developed by intergrowth into compact masses filling the interspaces between the grains. Together with the silica above mentioned, they constitute the bonding material for the rock. The average diameter of the grains of this sandstone is about 0.3 to 0.4 millimeter." Plate XX, number 5, shows the appearance of this sandstone in thin section under polarized light, magnified 20 times.

Harbison Quarry at New Martinsville, Wetzel County.

The Harbison sandstone quarry is located two miles below the town of New Martinsville, just above Sardis on the Ohio river and near the electric car track over which the stone is hauled to town. The stone has a very uniform texture. It is composed of small quartz grains, with mica flakes scattered through. It has a buff to yellowish brown color, but weathers to a lighter shade bordering on a gray tone.

Quarry. The face of the quarry runs east and west and is worked to the south with a present width of about 25 feet. Six men are employed and 100 perch were quarried during the summer of 1907. The Washington coal comes just below

the sandstone and was formerly mined on a small scale. A section of the quarry shows:

	Feet.
Red shales	12 to 20
Hard sandstone	3
Buff sandstone	12 to 15

The joint planes run north and south and N. 80° W. Between the latter planes the distance is 8 to 10 feet.

Further south large blocks of this sandstone have rolled down the hillside and are there blasted for rubble stone. At this place the stone is fine grained, silvery in lustre due to the abundant white mica flakes. It is also quite flaggy so that it readily splits into smooth blocks.

MANNINGTON SANDSTONE.

Charlton Quarry at Mannington, Marion County.

At the west edge of the city of Mannington, J. D. Charlton has opened a small quarry which has supplied stone for the city for several years. The floor of this quarry is 50 feet above the creek level in the city. Oil wells at this lower level strike the Pittsburg coal at a depth of 400 feet, which gives an interval of 450 feet between this coal and the sandstone at the quarry.

At Farmington, seven miles east, the interval between the Pittsburg and Waynesburg coals is 426 feet which is exceptionally large. A coal one foot thick outcrops along the railroad west of Mannington probably 30 feet below this sandstone, which is the Waynesburg "A" coal. The sandstone above would then represent a horizon not heretofore named, and it is therefore called the Mannington Sandstone. The stone has a greenish gray color and is finely laminated along planes formed of black mica. The quartz grains are very small giving the rock a close texture and white and black mica specks occur all through the stone, though especially abundant along the foliation planes.

Quarry. The face of the quarry runs N 40° W and is

75 feet long and worked back 30 feet. Below the sandstone is a heavy shale formation reaching down to the road 20 or 30 feet. A section of the quarry shows,

	Feet.
Shales	4
Buff, shaly sandstone	15
Blue and buff sandstone	6
Shales.	

The joint planes run N 60° to 70° W and N 40° W. A few curved joint planes were observed starting at an angle of N. 12° W. and changing to N. 30° W.

WAYNESBURG SANDSTONE.

This sandstone near the base of the Dunkard Series has been quarried more extensively than any other in the State, and it has proved a very valuable stone for buildings, railroad and bridge construction. It is usually a thick and resistant stratum forming bold cliffs and escarpments in the different valleys where it has been exposed by erosion. Its outcrop is prominent in many counties of western portion of the State. In the northern part the Waynesburg coal is found a few feet lower, but in Pleasants, Wood, Ritchie, Tyler, and other neighboring counties, the coal has disappeared so that the lower uneven surface of the sandstone rests on red shales. Its coarse texture, in places conglomeritic shows a shallow water origin, a conditon favorable to strong currents which would remove the coal stratum if this was present.

Dr. I. C. White states (Vol. II p. 117) that there is some evidence of marked erosion in this part of the series in southwestern part of the state, as the underlying Monongahela Series is there 100 feet less than at the north, and the Waynesburg coal is seldom found. The Waynesburg sandstone was named by the Pennsylvania geologists from its occurrence in the cliffs along Ten Mile Creek east of Waynesburg.

Dr. White in the report quoted above gives the following description of this sandstone. "The Waynesburg sand-

stone has a very wide distribution, extending as a great, coarse deposit entirely across the state. Being seldom less than 50 feet and often 75 feet in thickness it makes a line of rugged cliffs along its eastern outcrop from where it enters the state in Monongalia County, across Marion, Harrison, Lewis, Gilmer, Calhoun, Roane, Kanawha, Putnam, and Cabell to where it leaves the Appalachian trough in Wayne county near the Big Sandy. It is especially massive and pebbly where it rises from the bed of Poca river just below Walton and for many miles down that stream, as well as in all the country to the southward where the southeastward rise of the strata carries it up into the hill tops before it disappears from the same a few miles west from Elk river.

"This same stratum comes out of the Ohio river along the Ohio shore in the vicinity of Blennerhassett Island, and its massive top is frequently visible at low water in the bed of the Ohio at many localities between Parkersburg and Letart. Here the Ohio river veers to the northwest and the emergence of the Waynesburg sandstone makes "Letart Falls." It appears to be this same stratum that forms the great cliffs along the B. & O. railroad between Ellenboro and Cairo, as well as along Hughes river for long distances above McFarlan.

"It usually makes a good quarry rock for piers and other large structures, as it splits readily into great blocks of any desired size, dresses easily, and resists weathering action fairly well. It has frequently been used for bridge piers along the line of the B. & O. railroad in Marion, Harrison, Ritchie and other counties.

"In its western outcrop in Ohio, Marshall, Wetzel and Tyler counties, this rock, while occasionally massive, is not nearly so thick nor coarse as on the eastern side of the Appalachian basin."

Hoover and Kinnear Quarry at Muses Bottom, Jackson County.

Muses Bottom is a station on the Baltimore and Ohio railroad, Ohio river division, one mile and three-fourths be-

low Murrayville and about 26 miles below Parkersburg. At this place on the Noble farm a sandstone quarry was opened in 1903, and since 1905 has been operated by Hoover and Kinnear of Wheeling. In August, 1906, a second quarry was opened a mile south of the Noble farm. The rock comes at the horizon of the Waynesburg Sandstone.

The stone varies from a light gray to a light buff in color, and is more or less banded by white mica flakes. The gray stone is close grained but under a small lens is seen to be composed of well marked quartz grains. Some of the layers are conglomerates with the pebbles loosely held together and enclosing vitreous quartz fragments reaching a length of three-fourths inch. In the main quarry face, large boulders or niggerheads are seen with reddish brown color on the surface but with very hard fine grained blue cores. Some of the stone layers are composed of a coarse sand which crumbles in the hand. Blocks are readily quarried 4x4x2½ feet in size, also 7x2x2 feet, and the output was shipped to Wheeling where it was used in the piers of the elevated track of the B. & O. and for building stone.

Quarry. The quarry is located on the point of a hill with the face east and west and is worked to the north. The cover is 6 feet, but when the stone is followed back into the hill, this will increase to 20 and 40 feet.

A section of the quarry shows,

	Feet.
Shaly sandstone and soil	6
Sandstone, irregularly seamed	10
Gray sandstone ledge	10
Gray sandstone ledge	18
Gray sandstone ledge	17
Gray pebbly sandstone	10

The new quarry, one mile below, shows a 35 foot face with the lower third yellow or buff in color, and the upper portion light gray color similar to the upper quarry. The cover is 15 feet and the quarry is located in a ravine so that the stone is worked on both sides with railroad switch at center. This gives a double face of stone increasing the capacity. Physical tests on this stone are given in chapter XXVI.

Microscopical Structure. Mr. S. L. Powell gives the following report of his microscopical study of a thin section of this sandstone: "The rock as seen in the hand specimen and the thin section, is a mixture of quartz, decomposed feldspar, kaolin, white and black mica, iron oxide, together with some argillaceous matter.

"The feldspar is almost entirely decomposed only a few altered fragments remaining. The decompositon of the feldspars has resulted chiefly in the formation of kaolin, muscovite or sericite, which frequently form finely fibrous compact areas. The sericite together with the iron resulting largely from the decomposition of the biotite, frequently form the matrix of the stone. Some secondary silica has developed, but not in sufficient quantity to firmly cement the quartz grains. The large quantity of yellow oxide of iron gives the color of the rock, and constitutes part of the cement. The abundance of decomposed feldspar, kaolin, and argillaceous material, renders the rock soft and friable The quartz grains average about 0.4 millimeter in size.

Murray Brothers Quarry at Murrayville, Jackson County.

Murray Brothers of Wheeling operate a quarry in the Waynesburg sandstone at the station of Murrayville on the Ohio river division of the Baltimore and Ohio railroad. The quarry was opened in 1899 and the company has under lease about 80 acres of land. The stone has been used in the B. & O. pier work at Wheeling and in foundation work there. About one car load of stone is shipped daily and nine men employed at the quarry.

Quarry. The quarry face runs east and west about 400 feet long, and is worked toward the south away from the railroad. The face is 38 feet high and the stone can be worked 6 feet lower, giving a total height of 44 feet. The upper six feet of the rock has a lighter buff color, is softer and more or less shaly. The cover consists of three feet of soil.

In the upper portion of the quarry occurs a number of hard nodules or niggerheads, one of which was measured 15

feet long and 12 feet thick. Around these nodules the rock is shaly and poorer in quality. White flint pebbles occur here and there through the sandstone.

The joint planes run N. 80° W and N 60° E, also the main face joints nearly east and west. The joint planes are frequently curved and some come together forming triangular blocks. The joints are 16 to 25 feet apart so that large blocks can be quarried.

McCabe Quarry at Sistersville, Tyler County.

A sandstone quarry was opened about 12 years ago on the hill at the east end of the town of Sistersville near the Ohio river. It has been operated for the past two years by George McCabe for local trade. The quarry is now worked back almost to the lot lines. The horizon appears to be that of the Waynesburg sandstone.

Quarry. The face of the quarry is 150 feet long and it has been worked back 30 to 40 feet. The stone shows a strong dip to the east. As this stratum is followed north or south, it is claimed to be harder and more difficult to work, and is apt to be banded by silver streaks due to mica.

The quarry floor is 54 feet above the Baltimore and Ohio railroad track in the town, and a section shows:

	Feet.
Soil and shales	10
Fine shales	3
Sandstone ledge	2
Sandstone ledge	2
Sandstone ledge	6
Shaly sandstone	3
Greenish and black shales.	

The joint planes run N. 50° W. and N. 20° E.

Naughton Quarry at Cornwallis, Ritchie County.

Cornwallis is a small town on the main line of the Cincinnati and Grafton division of the Baltimore and Ohio railroad, 30 miles east of Parkersburg. In this locality quarries have been worked for forty years. The line of old

quarries extends for four or five miles along the railroad. The sandstone here forms abrupt cliffs along the creek valley and is correlated with the Waynesburg Sandstone. The underlying Monongahela Series appears to have been greatly eroded, and the coal is gone.

At the present time only one quarry is operated in this area along the railroad. It is located a short distance west of the Cornwallis railroad station and has been worked for 12 or 15 years by Michael Naughton. This quarry has been one of the largest in the State. A few years ago 30 to 40 men were employed and 50 to 60 cars of stone were shipped a month. At the present time 3 to 5 men are employed and about one car shipped daily during the working season.

The stone has a buff or yellowish brown color, and is coarse in texture. It is composed of small rounded grains of white quartz with the groundmass of brown particles. The quartz grains are loosely cemented so that the stone readily crumbles but becomes more resistant after exposure to the air. Mica flakes occur through the stone, but are not abundant. and the rock is pitted with white, kaolin particles which give it a speckled appearance very characteristic of this sandstone wherever found in western part of the state.

The stone has been shipped to Clarksburg and Parkersburg for buildings, but its great use has been for bridge piers especially along the B. & O. railroad, and it is regarded as one of the best bridge stones in the state. A car of bridge stone contains 25 to 30 yards, and a car of rubble or building stone contains 35 to 40 yards.

Quarry. The floor of the quarry is 118 feet above the B. & O. track, and about 100 feet above the car loading platform at the switch. An incline track and cable carries the stone from the quarry to the track below.

The quarry face runs east and west 100 feet, and is worked back about 40 feet. The cover consists of 8 to 10 feet of weathered stone and shales, and the height of the quarry face is 30 to 35 feet. Its top consists of 3 feet of light gray soft stone, and the bottom ledge of 10 feet shows a layer of reddish stone 2 to 4 feet thick at its base.

To the west across a small ravine is a second quarry (see plate XVI) also worked by Mr. Naughton, and the stone here shows a similar thickness and character. In the face of these quarries, a few large nodules or niggerheads occur, five feet in diameter, but they are not as abundant as in the Ohio river quarries in this same sandstone. Some of the quarry ledges are banded, and in some of the rock, brown soft sand spots occur, and these breaking out leave the blocks quite porous.

The joint planes run N 10° E, N 50° E, N 30° W.

The physical tests on this stone are given in chapter XXVI.

Chemical Analysis. An average specimen of this quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	95.78
Iron and alumina	2.73
Lime oxide	Trace
Magnesium oxide	0.15
Moisture and loss	1.50

This analysis shows a very pure sandstone, with low percentage of impurities.

Microscopical Structure. Mr. S. L. Powell makes the following report on a thin section of the Cornwallis stone (see plate XX, number 2): "The rock is composed of moderately well rounded, also angular quartz grains, a considerable amount of feldspar and kaolin. There are a few flakes of biotite, also a few garnets.

"The cement is in part silica, and partly yellow oxide of iron which together with a dark oxide lines the cavities and surrounds the individual grains. Some portions of the rock section contain quartz grains cemented by silica.

"The feldspars are generally much altered, and some of them completely broken down into a mosaic of secondary minerals. The biotite is also much altered, and the color of the rock is due to the large amount of yellow oxide of iron present. The quartz grains average about 0.6 millimeter in size."

Zinn and Moats Quarries at Harrisville, Ritchie County.

Harrisville is the county seat of Ritchie county, located five miles southeast of Cornwallis, and connected by a nine mile narrow guage railroad with the B. & O. at Pennsboro. The Waynesburg sandstone outcrops in the hills around Harrisville, and has been quarried for many years for local supply.

The stone at the Zinn quarry just west of town at the side of the county road is similar in color to that at Cornwallis but has a more compact texture. A section of this quarry shows:

	Feet
Cover of soil and broken stone	3
Shaly sandstone	3
Gray to brown sandstone	12
Brown sandstone	10

One-half mile southwest of town, is the Moats quarry with face 50 feet long east and west, and is worked back to the the south 8 to 10 feet. The stone is fine grained in texture, light gray or blue in color. Small flakes of white mica occur through the rock, also small spots of biotite flakes. The stone can be carved and works free in all directions. It was used in the ornamental front of the First National Bank building at Harrisville, and if worked on a larger scale should make a profitable quarry. The floor of the quarry is three feet above the creek level. The cover soon increases as followed back into the hill which rises 100 to 150 feet, and is composed of shales and sandstone ledges.

A section of the Moats quarry shows:

	Feet.
Light buff irregular stone	8 to 10
Gray sandstone, breaks shaly	4
Brownish gray sandstone	2
Gray or blue sandstone	6
Brownish sandstone	4

The joint planes run N 40° E, N 40° W, also east and west.

Plate XVII.—Georges Creek Coal and Iron Company Quarry in Waynesburg Sandstone at Underwood, Marion County.

Wilcox Quarry at Downs, Marion County.

At Downs, four miles east of Mannington, the Gilboy sandstone is well exposed in the railroad cuts; and higher on the hill another sandstone is quarried on the Bartlett farm, one half mile north of town, by A. R. Wilcox. The floor of this quarry is 70 feet above the creek level at the edge of town. A coal is found 18 feet lower than this sandstone on the hill just west of town, at the horizon of the Waynesburg coal, so this sandstone is the Waynesburg.

The sandstone at this small quarry is buff to grayish buff in color with large quartz grains giving a coarse texture. The rock is hard but crumbles readily and contains numerous white kaolin particles, also white mica flakes here and there. Some of the layers are conglomerates.

Quarry. The quarry face is 100 feet long east and west and is worked back 20 feet. The rock dips north into the hill, and the face of stone now exposed is 10 feet high but the rock continues down 10 or 12 feet further. Very little stone is now quarried and no work was done in 1907. The joint planes run N. 30° E and N 20° W, with a few north and south joints.

Georges Creek Coal and Iron Co. Quarry at Underwood, Marion County.

Underwood station or Farmington post office is located three miles east of Downs on the B. & O. railroad. The Georges Creek Coal and Iron Co., operate a quarry opened in 1905 on the hill above their mines. The floor of the quarry is 160 feet above the top of the mine shaft which reaches the Pittsburg coal at 250 feet, or an interval of 410 feet between the coal and the quarry. The Waynesburg coal outcrops just below the sandstone, which is therefore the Waynesburg sandstone. The Gilboy sandstone below the Waynesburg coal was formerly worked at this same place.

This sandstone is coarse grained more or less open in texture with distinct quartz grains, white and black mica. The buff or light brown sandstone is iron stained. The blue or gray stone has a similar texture to the brown and is some-

what laminated. The color in the exposed portions of the quarry shows a tendency to brown shades, but the blue stone when not stained by water is durable in color. The quality and color of the rock should make it a very desirable stone especially for trimmings.

Chemical Composition. An average lot of the sandstone from this quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica	82.14
Iron oxide	3.71
Alumina oxide	9.04
Lime oxide	0.37
Magnesium oxide	0.32
Alkalies	2.69
Moisture and loss	2.04

Quarry. The face of the quarry runs N 60° W and is about 250 feet long (see plate XVII). The floor is 170 feet above the B. & O. track and the stone could be delivered by incline to the cars and shipped in any direction. The stone has been used in buildings and walls in the town but is mainly used by the coal company for their houses, mine buildings, and coke ovens. The quarry shows the following section:

	Feet.	
Soil	1	
Shales and shaly sandstone	4	
Coarse sandstone, banded	9	
Coarse brown sandstone	4	
Coarse blue sandstone	4	(cross bedded)
Brown fairly coarse sandstone	6	
Blue fine grained sandstone	4	
Blue fine grained sandstone	9	

The joint planes run N 60° W and N 20° E. The physical tests on this sandstone are given in chapter XXVI.

C. B. Conoway Quarry Near Barracksville, Marion County.

For many years the heavy sandstone ledge high in the hills half way between Farmington and Barracksville near the Baltimore and Ohio railroad have been worked. The locality is eight miles west of Fairmont. This horizon just above the Waynesburg coal is the Waynesburg sandstone. The only quarry now in operation is owned by the C. B.

Conoway, and the stone is shipped mainly to Fairmont where it is used for building and bridge work. The retaining wall at the Fairmont depot was constructed of this stone in 1897. The piers of the old suspension bridge at Fairmont and the new piers recently constructed were of the Waynesburg sandstone from the Conoway quarry.

This sandstone is a yellowish gray to gray in color. It is coarse grained, pebbly in places, and marked by the usual white kaolin spots. The yellow or buff color in some of the ledges is due to iron.

Quarry. The floor of the quarry is 207 feet above the B. & O. track. The face runs parallel to the joint planes N 50° W and is about 250 feet long and worked back 20 to 30 feet. A section of the quarry shows:

	Feet.	Inches.
Soil cover	3	
Shaly sandstone	1	
Flaggy sandstone	2	
Sandstone ledge, gray	5	
Sandstone ledge, gray	0	10
Buff sandstone	9	

Near the north end of the quarry the following section was measured:

	Feet.	Inches.
Soil and clay	3	
Shaly sandstone	5	
Sandstone ledge	2	6
Shaly sandstone	0	6
Sandstone ledge	5	
Buff sandstone	4	
Coarse, blue sandstone (banded calico stone)	6	
Coarse, blue sandstone (pebbly in places)	4	6
Shaly sandstone, cross bedded	0	6
Coarse sandstone	2	6

In this last section the four foot buff sandstone represents the bottom of the first section, the quarry being worked nearly 14 feet deeper at this place.

The joint planes run N. 80° E. and N. 50° W., the latter planes give the working face of the main quarry, though in parts of the quarry the working face is nearly north and south. The physical tests on this stone are given in chapter XXVI.

CHAPER XXI.

THE SANDSTONES OF THE MONONGAHELA SERIES.

Gilboy sandstone.
Uniontown sandstone.
Sewickley sandstone.
Upper Pittsburg sandstone.

GILBOY SANDSTONE.

This sandstone is often found five to ten feet below the Waynesburg coal, and was named by Dr. I. C. White, from its outcrop in the Gilboy cut on B. & O. railroad just east of Mannington. Dr. White describes the Gilboy sandstone as follows, (Vol. II, p. 150): "The stratum in question is a very hard, rather fine grained, grayish white rock, seldom containing any pebbles and when present forms a bold cliff or bluff below that of the Waynesburg pebbly sandstone above. It is especially prominent in Marion, Lewis, and Gilmer Counties."

The stone has been quarried at several points along the railroad near Downs, and an old quarry is located just below the Waynesburg sandstone quarry at Underwood or Farmington.

Georges Creek Coal and Iron Company Quarry at Underwood

The Underwood Gilboy sandstone quarry of this company is 40 feet lower than the Waynesburg sandstone quarry described in the last chapter. Its floor is 165 feet above the top of the coal shaft, or 375 feet above the Pittsburg coal in this shaft, and the sandstone is just below the Waynesburg coal, or at the horizon of the Gilboy sandstone. The quarry was worked for a number of years and an incline track led

from it to the county road and railroad below, but it is now abandoned.

Quarry. The sandstone is buff to brown in color on outcrop and rather fine grained. It is almost impossible to tell the color of the unweathered stone at the present time. A section of the quarry shows the following ledges:

	Feet.	Inches.
Shale and soil	3	
Coal, Waynesburg	1	
Limestone, nodular	0	6
Shales	3	
Sandstone, shaly	5	
Sandstone ledge	2	
Sandstone ledge	2	
Sandstone ledge	2	
Sandstone ledge	0	6
Sandstone ledge	0	8

UNIONTOWN SANDSTONE.

The interval between the Uniontown and Waynesburg coals in the typical section contains shales, thin limestone and coal layers with no well marked sandstones, but at a number of localities a massive sandstone is found above the Uniontown coal horizon, and named the Uniontown Sandstone.

McGeorge Quarry at Clarksburg, Harrison County.

In 1900, Mr. David M. McGeorge opened a sandstone quarry at the top of a high hill one mile south of the city of Clarksburg. The level of the quarry is 320 feet above the Post Office, or 1,327 feet above tide. The floor of the quarry is 235 feet above the Pittsburg Coal formerly mined on the north slope of the same hill. According to the section made on Pinnickinnick hill north of town and given in the description of the next quarry, this sandstone should correspond to the one quarried on the Jackson farm, and would represent the Uniontown Sandstone.

The sandstone is blue in color below, and brown or buff in other ledges. It is fine grained in texture, with spots of iron oxide and considerable mica. The mica flakes are frequently in bands giving the rock a foliated or striated appearance. The buff stone is quite permanent in color, but

the blue weathers to brown or buff where it is exposed in the quarry, and it becomes tinged with buff shade where exposed in old walls.

Quarry. The quarry face as opened is about 600 feet long east and west, and has been worked back to the north 20 to 40 feet, and is 20 feet high. The cover of soil and shale is shallow, one to three feet thick, but farther back the hill rises 30 feet higher. The bedding planes cause the stone to break readily in quarrying into ledges one to four feet thick as shown in the following section:

	Feet.	Inches.
Soil cover	1	
Shaly sandstone	3	
Shaly sandstone	2	6
Buff and blue sandstone	1	6
Buff and blue sandstone	2	
Buff and blue sandstone	1	
Buff and blue sandstone	1	
Buff or brown sandstone	3	4
Buff or brown sandstone	2	
Blue sandstone	4	
Total	21	4

The main joint planes run N. 45° E. and N. 45° W., with another set nearly due north and south. Many of these planes are curved, and there appear on blasting numerous diagonal joint or fracture planes which cause the stone to break into irregular blocks. Cross bedding structure is seen in many places.

The stone has been quarried for stone walls, and foundations of buildings; but during the past two years most of the stone has been crushed for concrete, which has yielded a good profit with a more constant demand than in the building stone trade.

The daily capacity of crushed stone is 50 to 60 yards, selling at one dollar a yard at the quarry, or two dollars in town. Most of the stone on account of its irregular shape, foliation, and changeable color, is not well adapted to use as building stone. The best stone is apparently confined to the west end of the quarry.

Jackson Quarry at Clarksburg, Harrison County.

On the T. M. Jackson land on Pinnickinnick hill just north of the Baltimore and Ohio railroad at Clarksburg, a sandstone quarry has been worked more or less for 30 to 40 years. It has been operated for the past few years by Daniel Limer under lease. The level of the floor of the quarry is 240 feet above the Pittsburg coal, 276 feet above the B. & O. track, or about 1,290 feet above tide.

The floor of the McGeorge quarry, one mile and a half south is 37 feet higher, while the difference in level of the Pittsburg coal in that distance is 42 feet, giving a north dip of 28 feet to the mile. This sandstone is locally called the Waynesburg, but according to the following accurately leveled section of Pinnickinnick hill by Mr. J. L. Johnson (Vol. II, p. 140), it is 90 feet or more too low for the Waynesburg horizon.

SECTION OF PINNICKINNICK HILL.

	Ft.	In.	Ft.	In.
Coal, Waynesburg, absent or not seen			0	0
Concealed and yellow sandy shales	65	0		
Sandstone	25	0		
Concealed, with some limestone	80	0		
Sandstone	20	0		
Concealed	5	0	251	0
Sandstone	15	0		
Sandy shales	6	0		
Sandstone, SEWICKLEY	25	0		
Shales	10	0		
COAL, SEWICKLEY			1	0
Limestone { shaly 1′ 6″; good 7′ 6″ }	9	0		
Concealed	3	0		
Shales, sandy	14	0		
Shale, with iron nodules	1	0	40	0
Shales, sandy	4	0		
Sandstone	1	0		
Concealed	8	0		
Coal, REDSTONE, slaty			3	0
Shale, dark, bituminous	5	0		
Limestone, Redstone	6	0	25	0
Shale, greenish	13	0		
Slate, bituminous	1	0		
COAL, PITTSBURG { coal	3	5		
COAL, PITTSBURG { bone	0	1	8	6
COAL, PITTSBURG { coal	5	0		
Total			328	6

The sandstone in the Jackson quarry corresponds very closely in position to the Uniontown Sandstone described by Dr. I. C. White (Bull. 65, U. S. G. S., p. 58), and would represent that horizon. This sandstone was described in southern Pennsylvania, and has not been identified in the West Virginia sections.

The sandstone has blue or gray color, fine grained texture and has been quarried only on a small scale, and no stone is shipped away from the city. It is used for foundations, trimmings, and walls. The Presbyterian church at Clarksburg was built of this stone in 1893, and the Lowndes bank building in 1896 was trimmed with the Jackson stone. It has been used in a number of yard walls, one of the best examples being seen in the fence or wall around the Jackson home. In all of these structures the stone shows no ill effects of weather exposure, and the color change is very slight.

Quarry. The exposed face of the quarry (see plate XVIII) is 130 feet long east and west and worked back 30 to 40 feet. The cover consists of finely laminated shales 6 to 10 feet thick. A section of the quarry shows the following ledges:

	Feet.	Inches.
Shales	6 to 8	
Sandstone	1	8
Sandstone, with buff tinge	6	
Shale	0	10
Blue sandstone	6	
Blue sandstone	1	10

The joint planes run N 14° W, N 10° W, also nearly east and west, and a few are found N 50° E. The number of joint planes causes the stone to break into rather small blocks. A common size of the blocks quarried is 18x18x30 inches. The physical tests on this stone are given in chapter XXVI.

Chemical Composition. An analysis of the sandstone from the Jackson quarry was made in the Survey laboratory with the following results:

	Per cent.
Silica	89.62
Iron and alumina	6.01
Lime oxide	0.92
Magnesium oxide	0.77
Moisture and loss	2.48

This analysis shows the sandstone contains considerable foreign matter, especially alumina and iron, but is low in lime and magnesium.

Microscopical Structure. Mr. S. L. Powell makes the following report on the thin section of the sandstone at the Jackson quarry:

"The original constituents of this fine grained sandstone were quartz and feldspar in about equal proportions with a less amount of biotite mica and kaolin, with a few grains of zircon. The quartz grains are exceedingly varied in outline, from small broken fragments to sharply angular, ragged, and elongated forms. The largest grains are not more than 0.6 millimeter in length, and the average diameter is about 0.25 millimeter.

"A certain amount of silica has developed between the grains when in contact or nearly so, forming the cement at these places. Occasionally a bond of silica is observed between the quartz and fresh feldspar. Most of the feldspars however, are more or less altered to calcite, sericite, and kaolin. Calcite and muscovite mica often appear filling the interstices. The secondary minerals, calcite, chlorite, muscovite, frequently form matted masses between the grains; or as fibrous strands intricately extend around and among the grains uniting several areas, simulating flow structure in certain igneous rocks.

"The biotite as a rule is much altered and leached of its iron, and a number of crystals of iron pyrites were observed. Under crossed nicols in the microscope, the section shows a rich mosaic of quartz and twinned feldspar in a finely fibrous, velvety matrix of chlorite, muscovite or sericite, and calcite."

Riggs Quarry at St. Marys, Pleasant County.

In the river bluffs around St. Marys on the Ohio river there is a heavy sandstone stratum with a small coal vein below. This rock has some resemblance in texture and structure to the Waynesburg sandstone but the interval below it to the oil and gas sands is too short, for this horizon. There is evidence of erosion below it to account for the shortened

interval, and Dr. I. C. White, in Volume II (p. 149) suggets the correlation of this rock with the Uniontown sandstone. In the county report on this area now in preparation, the detailed structure will be worked out and the correlation may be changed. For the present the St. Marys sandstone will be placed in this section.

The Zack Riggs quarry is located at the lower edge of the town of St. Marys up a little ravine, locally called Tanyard Hollow. The stone is granular and the grains small giving a fine texture. A few layers show a pebbly sandstone or conglomerate. The color varies from a blue or yellowish stone to buff. The stone is quarried on a small scale and used in the town.

Quarry. The face of this quarry runs N 20° W and is 140 feet long and worked back at the top 20 feet giving a slanting outcrop. The rock dips N 40° E at an angle of 12 degrees. A section at the center of the quarry shows:

	Feet.
Red clay	4
Red shales	3
Sandstone, foliated and broken	4
Buff sandstone	10 to 12
Blue sandstone	2[1]

At the north end of the quarry the following section was measured:

	Feet.
Soil	3
Sandstone, buff	8
Sandstone, blue	10

Across the ravine below this last section, the rocks are exposed as follows:

	Feet.	Inches.
Shales, buff	2	
Shales, blue and black	2	
Coal	1	2
Clay and shales	10	

The joint planes run N 70° E and N 50° W.

1. I find there has been wide-spread erosion at the time of the deposition of the Waynesburg sandstone and it is quite probable that the St. Mary's SS. may be Waynesburg and the underlying coal Uniontown. I. C. White.

SEWICKLEY SANDSTONE.

Dr. I. C. White in Volume II (p. 152) gives the following description of this sandstone:

"Along the eastern crop of the Monongahela series, a thick, massive sandstone frequently comes into the section and cuts out a large portion of the Great Limestone. This sandstone overlies the Sewickley coal closely and hence has been termed the Sewickley sandstone. It is especially prominent along the Monongahela river between Morgantown and Fairmont and may be seen making great cliffs opposite Beechwood, where it is 60 feet thick. Through Harrison, Lewis, Gilmer and other southwestern counties along the line where the Monongahela series crops to the surface, the Sewickley sandstone, together with the underlying Pittsburg sandstone, often forms a bold cliff rising to the height of 125 to 150 feet above the horizon of the Pittsburg coal.

Occasionally the Sewickley sandstone is a good building rock, as at the Stokes Tunstill quarry, high up in the hill along Polk Creek, two miles south from Weston."

Mr. J. Fay Watson owns a quarry located on the hill about one-fourth mile west of the court house at Fairmont, which he has operated since 1900. This stone has been used in the high wall around the Watson addition, in a number of houses and business blocks. This stone is very close grained in texture with a greenish to bluish gray color. Mica is not abundant, but in some ledges the black mica gives a speckled appearance to the rock. The color is quite permanent in buildings, though in the old quarry exposures, the stone changes to a brownish gray color due to iron which may be seen in round dots through this rock. The sandstone splits readily into desired shape, and is a very valuable quarry stone.

There has been some difference of opinion as to the proper correlation of the Watson stone. The floor of the quarry is 180 feet above the Pittsburg coal and above the roof comes a heavy limestone which corresponds to the Uniontown. Higher in the hill, probably 180 to 200 feet, the Waynesburg coal has been opened. The interval between the Pittsburg and Sewickley coals at Fairmont is about 120 feet, and to the

Waynesburg coal 400 feet. With due allowance for increase in the interval through the dip of the rocks, this sandstone is too high by 25 or 30 feet for the normal interval to the Sewickley sandstone. However, this sandstone shows along the Monongahela river an unusual thickness of 60 to 80 feet, and the Watson quarry is not worked to the bottom of the sandstone. From the relation of this rock to the other well defined strata, it is in all probability the Sewickley Sandstone.

Quarry. The face of the quarry runs east and west about 220 feet in length and is worked back to the north 15 feet by stripping, and then is tunneled under the limestone cover 20 to 25 feet. Most of the stone now used at this quarry is obtained from these tunnels or rooms, one of which is 14x20 feet. Pillars of the sandstone are left to support the roof. A section of the quarry shows:

	Feet.	Inches.
Soil and clay	2	
Red shales	4	
Limestone in nodules	4	
Shaly limestone in nodules	4	
Blue calcareous shales	5	
Shaly sandstone	0	4 to 6
Blue or greenish sandstone	3	
Greenish or blue sandstone	4	
Greenish or blue sandstone	4	6
Buff sandstone	7	

The whole overlying formation increases in thickness as followed to the west, reaching 30 feet, and the stone has a pronounced dip to the west. The sandstone splits readily, but is a hard rock and breaks more irregular across the bedding.

The joint planes run N 30° W and N 50° E. Some irregular fractures run N 20° W. One smooth fissure open for a width of three inches runs N 30° W, but on the opposite wall it starts at an angle of N 50° W, and farther in is again N 30° W. The planes N 30° W are one to eight feet apart, while those running N 50° E are one to five feet apart.

The physical tests on this stone are given in chapter XXVI.

Microscopical Structure. Mr. S. L. Powell gives the following report on a thin section of the Sewickley sandstone from the Watson quarry: "This rock is a heterogeneous mix-

Plate XVIII.—Jackson Quarry in Uniontown Sandstone at Clarksburg, Harrison County.

ture of quartz grains and feldspar (orthoclase and plagioclase) in nearly equal proportions. The other original constituents are kaolin, mica, and a few zircon crystals. In addition, there are a number of minerals which are evidently of secondary development; such as silica, calcite, kaolinite, chlorite, epidote, muscovite or sericite, and iron oxide. These minerals are mostly alteration products of the original minerals noted above, together with other ferromagnesian constituents in all probability originally present.

"These secondary minerals have so intergrown as to form a compact matrix or cement for the remaining original minerals. The quartz grains possess a very irregular outline due to secondary enlargement by silica. Some of the feldspars are fresh and clear, while others are either kaolinized or completely altered. The average diameter of the quartz grains is about 0.25 millimeter.

UPPER PITTSBURG SANDSTONE.

Dr. I. C. White in Volume II (p. 163) describes this sandstone as follows:

"In the Fairmont region and especially along the eastern crop of the Pittsburg coal, there is often found a thick, coarse, gray sandstone, usually very soft, and readily disintegrating when exposed to the weather. When this sandstone is present in a massive condition the overlying Redstone Coal and Limestone are nearly always absent. For instance on the east side of the Monongahela river at Morgantown, and on eastward to the Cheat river, the sandstone is present in a massive condition, only two to five feet above the Pittsburg Coal, while not a trace of the Redstone Coal is to be seen, but on the west side of the Monongahela, only two miles distant, the sandstone is gone entirely, while the Redstone Coal and Limestone are both present.

"When massive, the sandstone contains much feldspathic material and easily disintegrates into a bed of coarse sand where exposed along the roads, etc. It has been quarried to some extent for building stone in the Fairmont region,

but it furnishes a poor quality which stains badly and will not long endure the action of the elements.

"Southward through southern Lewis, eastern Gilmer, and southern Braxton a great cliff rock appears to come at this horizon, being very conspicuous for many miles above Glenville, on the Little Kanawha river, as well as southwestward through Braxton, Roane and Kanawha counties. It also forms conspicuous cliffs in the region of Hartford, Pomeroy, Point Pleasant and other localities along the Ohio river between Hartford and Huntington."

Charles Quarry at Point Pleasant, Mason County.

John Charles has operated from time to time for local use, a small quarry one-fourth mile southeast of the Baltimore and Ohio station at Point Pleasant. The original quarry was opened over 20 years ago. The sandstone when freshly quarried is blue in color, weathering in the exposed parts of the quarry to a buff color. It is filled with mica and has a foliated structure. The stone breaks in small blocks suitable for foundation work.

The sandstone outcrop comes 10 to 12 feet above a small coal blossom which is 75 to 80 feet above the Great Kanawha river and represents the Pittsburg coal outcrop so that the quarry rock would be the Upper Pittsburg Sandstone.

Quarry. The face of the quarry along a fairly smooth joint plane runs east and west. A section shows the following ledges:

	Feet.
Sandy shales and clay	2
Shaly sandstone	5
Buff sandstone	4
Red and brown shales	9
Buff and blue sandstone	15

The four foot ledge of buff sandstone is honeycombed through weathering. The lower 15 foot ledge in a portion of the quarry is divided near the center by one foot of blue shales, but this parting disappears as the stone is followed to the west.

Lilley Quarry at Fairmont, Marion County.

Mr. George Lilley has worked for the past few years a quarry opened many years ago at the east edge of Fairmont on Washington street. The floor of the quarry is about 60 feet above the Baltimore and Ohio track and it forms the roof of the Pittsburg coal. Very little stone has been taken out for the past two years.

Quarry. The face of the quarry runs nearly east and west with a length of 440 feet, and it has been worked to the north about 30 feet. The stone is rather coarse grained with iron spots here and there. The quartz grains are rounded and somewhat loosely cemented. Both black and white micas are abundant and arranged often in parallel planes giving a pronounced foliation. The ledges near the center of the quarry show cross bedding structure. The color of the rock is a blue or bluish gray, and weathers to a buff.

The sandstone dips to the northwest, and at the west end of the quarry the dip is rather heavy to the north. At this west end, the stone is foliated and contains numerous dark carbonaceous spots and streaks. The recent work has been at this place where there is a 10 to 12 foot face with a cover of 8 to 10 feet of shaly sandstone which breaks very irregular. The Pittsburg coal shows at this point under the sandstone.

The face of the old main quarry shows:

	Feet.
Buff shales	20
Shaly sandstone	2
Blue sandstone ledge	16
Blue sandstone ledge	9

The joint planes run N 10° W, and east and west.

Fay Watson Quarry at Fairmont.

In addition to the Sewickley sandstone quarry described above, Mr. J. Fay Watson has a second quarry in the ravine below the upper quarry, where the sandstone rests on the Pittsburg coal which can be seen in the creek bed.

Quarry. This quarry is about worked out to the lot lines and has been abandoned for several years. It shows, the following section:

	Feet.
Fine shales and soil	6
Shaly sandstone in thin layers	8
Blue sandstone, buff on outcrop	7
Shaly and cross bedded sandstone	6

Ice and Company Quarry at Fairmont.

William B. Ice and Company has opened a quarry one mile and a half east of the court house at Fairmont, near 11th street on the lands of the Fairmont Real Estate and Development Company, and not far from the B. & O. railroad. This quarry and the Watson upper quarry supply most of the building stone used in the city. The rock is over the Pittsburg coal and is therefore the Upper Pittsburg Sandstone. The stone is finely granular with small quartz grains, and a large amount of mica causing the stone to break along parallel planes. It has a light gray or bluish gray color and has a banded or foliated appearance. These bands often run at an angle with the bed, giving a cross bedding structure.

Chemical Composition. The sandstone from this quarry has the following chemical composition according to the Survey analysis:

	Per cent.
Silica	80.88
Iron oxide	0.85
Alumina oxide	12.56
Lime oxide	0.72
Magnesium oxide	0.57
Alkalies	1.90
Moisture and loss	2.99

Quarry. The face of the quarry runs northeast-southwest at about a 45 degree angle, 60 to 70 feet long, and is worked back about 40 feet. The stone on outcrop is buff to brown in color and shaly, but as followed into the hill becomes a light blue or gray. It is quarried mostly by means of plugs or wedges, very little powder being used.

A section of the quarry shows:

	Feet.	Inches.
Shaly irregular brown sandstone............	4	6
Buff sandstone	2	
Coarse sandstone, brownish gray............	2	
Brown or buff sandstone....................	1	
Buff shaly sandstone........................	0	3
Buff sandstone	0	6
Blue sandstone	1	6
Blue, foliated sandstone....................	8	

The joint planes run N 50° E and N 60° W. The physical tests on this stone are given in chapter XXVI.

Old Quarry. Some years ago Ice and Company worked a quarry a few blocks nearer town in this same sandstone, but it is now back to the lot lines, and has been abandoned. The quarry as worked out is 80 feet long and 30 feet wide. The rock is strongly banded and is fine grained in texture. A section of the quarry shows the following ledges:

	Feet.
Soil and clay cover	3
Shaly sandstone	3
Buff sandstone	1½
Blue sandstone	1
Blue sandstone	8
Crumpled, shaly blue sandstone........................	1
Strongly banded, blue or gray sandstone..............	4
Blue or gray sandstone, to water level................	3

This quary is now partly filled with water so that the lower portion of the face could not be observed.

CHAPTER XXII.

THE SANDSTONES OF THE CONEMAUGH SERIES.

Lower Pittsburg sandstone.
Connellsville sandstone.
Morgantown sandstone.
St. Albans sandstone.
Saltzburg sandstone.
Buffalo sandstone.
Mahoning sandstone.

Lower Pittsburg Sandstone. Below the Pittsburg coal there may be a series of shales, limestones, and thin seams of coal, but in many places there is a sandstone ledge. It is not quarried at any place in the state, and has no economic importance.

CONNELLSVILLE SANDSTONE.

The Lower Pittsburg limestone belongs in the Conemaugh series about 80 to 90 feet below the Pittsburg coal, and a few feet below this limestone is a massive sandstone named by Stevenson from its exposure at Connellsville, Pa., the Connellsville sandstone. Dr. I. C. White in Volume II (p. 247) gives the following description of this rock and its distribution:

"When massive, this rock is one of the finest building stones in the entire Coal Measures. The sand grains being cemented by silica and peroxide of iron, are almost weather-proof, so that for all structures like bridge piers, outside walls,

etc., it has no superior. The iron in the rock often permeates the entire mass so thoroughly as to give it a uniform reddish tint, and again it may have a speckled type, much resembling gray granite.

"The Asylum for the Insane at Weston, as also the B. & O. station building there, were constructed largely from this rock obtained at Mt. Clare, Harrison county, while the suspension bridge piers at Morgantown as well as the post office building there, are built of the same stratum. The suspension bridge piers have stood for more than fifty years; and exhibit no tendency to disintegration.

"The rock splits readily into any desired size and, although quite hard to carve into delicate shapes, yet it "masons" very readily into beautiful forms for natural or uncut "rock face" work.

"Being one of the chief rocks in the Conemaugh series, it has played a very important part in shaping their topography. It is especially hard, massive and often pebbly in the Potomac and George's Creek basin, and the rounded hills that hold the "Big" (Pittsburg) "vein" rest upon a platform of this Connellsville sandstone which, owing to its resistance to erosion, makes a bold terrace far up the mountain sides, after the Pittsburg coal and all other soft beds above its horizon have disappeared. It is this hard bed of pebbly sandstone that caps the summits in the center of the Potomac basin southwest from Elk Garden, forming almost level plateaus over thousands of acres where the great Pittsburg coal is missed by only a short interval.

"This stratum varies in thickness from twenty to fifty feet and may be seen making huge cliffs at many places along the Monongahela river between Morgantown and Fairmont. It is also conspicuous near the base of the hills at Berryburg, Barbour county, and at many localities along Elk Creek in Barbour and Harrison. It forms the principal quarry rock in the vicinity of Clarksburg, and is now extensively used at Morgantown, for all building work, street curb, etc.

"The interval between the Connellsville sandstone and the Pittsburg coal is seldom less than sixty feet, and often

ninety or more. When the sandstone is not present as a massive rock, its place is filled with sandy shales or flaggy sandstone."

Donlan Quarry at Weston, Lewis County.

The William Donlan sandstone quarry formerly worked by Abe Hale is located at the north edge of the town of Weston at the side of the Baltimore and Ohio railroad to Buckhannon. It has been opened for many years and has furnished much of the stone used in the town. During the last two years it has been operated under lease by John Riley.

The Redstone coal has been mined 200 feet above the floor of this quarry and the Elk Lick coal crops in the bed of the river 40 feet lower with the roof of Morgantown sandstone. The quarry sandstone is therefore the Connellsville. The unweathered stone has a bluish gray color, fine grained texture, with black and white mica scattered through giving a somewhat speckled appearance. The stone is slightly laminated, and splits readily into blocks of desired size and shape. Some of the ledges are coarse in texture showing larger quartz grains, and the stone weathers to a buff color in the exposed portions of the quarry.

Quarry. The face of the quarry runs northwest-southeast at an angle of 45° and is about 125 feet long and worked back 25 feet (see plate XIX). A section of the quarry shows:

	Feet.	Inches.
Soil and shales	5	
Buff sandstone	6	
Chocolate brown shales	15	
Blue and buff shales	3	
Blue and gray sandstone	1	
Shales	0	3
Greenish blue sandstone	7	
Blue sandstone	5	
Buff and blue sandstone	6	

The joint planes run N. 50° E. and N. 70° E.

Microscopical Structure. Mr. S. L. Powell gives the following description of the structure of this sandstone as determined from a microscopial study of a thin section:

"The sandstone has a granular structure and is rather porous, as the interstices between the grains are not completely filled. There was originally a considerable amount of feldspar which has for the most part altered to silica, muscovite, and kaolin. A few crystals are fresh enough to show the twinning lamellae characteristic of plagioclase feldspar. These crystals may be seen in all stages of decomposition. In some cases the original form of the crystal is preserved in its alteration product, and again it is completely broken down. The feldspar alteration products, silica, muscovite, etc., in the different areas unite to form large interlocking solid units. In such areas there are many centers from which the secondary quartz began to crystallize, as shown by the independent orientation of the various interlocking grains, now constituting the mass.

"The original quartz grains have in the majority of instances undergone enlargement by secondary silica, which in ordinary light is not discernible. The appearance is that of a large irregular homogeneous mass of solid quartz; but under crossed nicols, it can be seen to be an aggregate of grains from their independent orientation and the intricate manner in which they interlock, forming a compact body even to the minutest details of the boundary lines between the grains. Again a cloudy or shadowy margin marks the enlargement of the originally clear grain. In a few instances, grains were observed which had a coating of oxide of iron previous to the enlargement, and the exterior rim of secondary quartz orients with the original grain as in other instances of quartz enlargement.

"There is also considerable development of muscovite sometimes filling large interspaces, enclosing lenses of clearly crystallized calcite showing twinning lamellae. The quartz contains many gas and other small undetermined inclusions. The cement or matrix is therefore largely silica and muscovite, some calcite, with oxide of iron, but the siliceous material predominates. The quartz grains are angular, crushed, broken, and recemented; and many of them show undulatory extinction as the result of strain. In size the grains vary

from 0.1 to 0.9 millimeter, and would average about 0.4 millimeter."

Chemical Composition. A sample of the sandstone from the Donlan quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	93.45
Iron and alumina	3.73
Lime oxide	0.53
Magnesium oxide	0.46
Moisture and loss	1.88

Garrett Quarry at Weston, Lewis County.

The W. D. Garrett sandstone quarry on the Tom Hale property is located just north of the B. & O. passenger station at Weston and east of the track. The rock is at the same horizon as the Donlan quarry, the Connellsville Sandstone. This sandstone has a greenish color, very fine grained in texture, closely laminated in structure, and breaks with very smooth surfaces. In places the rock is gnarly or twisted in grain, and nearly all of it is very hard.

Quarry. The face of the quarry runs east and west 80 to 90 feet long and is worked back about 20 feet. The west end of the quarry has been stripped for 115 feet through 12 to 15 feet of shales to the rock, and this cover will soon increase to 20 or 25 feet. In the present working quarry the cover is lighter as shown in the following section:

	Feet.
Soil cover	8
Chocolate brown shales	10
Greenish sandstone	10
Greenish sandstone	6

The joint planes are one to five feet apart and run N. 30° to 40° E, also due east and west.

Porter Smith Quarry at Farnum, Harrison County.

The Porter Smith quarry was opened some years ago one mile below Farnum station on the Baltimore and Ohio railroad, seven miles north of Clarksburg. It supplied bridge

stone for the railroad, also building stone, and was worked until the death of the owner four years ago, and has not since been re-opened.

The Pittsburg coal is worked to the south high on the hill, probably 100 feet above this stratum, which is therefore the Connellsville Sandstone. The stone is buff to brown in color, but in fresh exposure has a light gray color. It is close grained with small quartz particles, spots of iron oxide, and very small white mica flakes. Some of the lower ledges are coarse grained.

Quarry. The quarry face runs north and south, 30 feet long and was worked to the east. The floor is only a few feet above the railroad track and rests on blue and buff shales. The cover as exposed in the quarry consists of 8 to 10 feet of shales and clay, which farther back in the hill will reach 50 feet. The sandstone becomes shaly on outcrop as followed north and south, but in the latter direction the stone is mostly concealed.

The quarry shows the following section:

	Feet.
Shales and clay	8
Shaly sandstone	2
Sandstone ledge	10
Sandstone ledge	15
Coarse buff sandstone	3
Blue and buff shales	3+

The joint planes run N. 30° E and N 45° W and the rock shows a pronounced dip to the west.

Wm. Cox Quarry, Near Morgantown, Monongalia County.

On the land of Wm. Cox one mile southwest of Morgantown a quarry in the Connellsville sandstone has been opened for 50 years or more. It furnished a large part of the stone for the piers of the old suspension bridge at Morgantown, and there it has proved to be a most durable stone after fifty years exposure.

The floor of the quarry is 150 feet above the Ames fossiliferous limestone, and 285 feet above the Buffalo sandstone

quarry at the lock near town. The rock has a grayish white color but weathers to a light brown or buff. Some of the stone is hard, very fine grained and uniformly dotted with red iron spots giving a mottled or speckled appearance, while other ledges are free from these iron spots. In some ledges the rock has a sugary or saccharoidal texture due to an aggregation of small, round, and transparent quartz grains.

Quarry. The quarry face runs N 40° E and is 150 feet long, worked back 30 feet. The stone can be quarried in blocks of almost any desired size. It splits readily parallel to the bed planes, and on account of its durability and size of blocks, it is a most valuable quarry stone.

This quarry has not been worked to any extent in recent years. The present supply of stone is obtained by breaking the large boulders that have rolled down the slopes of the hill. These are now blasted and cut for use in the city and constitute one of the main sources of stone supply in this section. The quarry was reopened in 1908 to supply a portion of the stone used in the construction of the piers of the new bridge now nearing completion across the river at Morgantown. A section of the quarry shows:

	Feet.	Inches.
Shales and soil cover	4	
Shaly sandstone	3	
Buff shales	6	
Coal blossom	0	3
Finely laminated shales	1	6
Sandstone ledge	16	

The joint planes run east and west 5 to 20 feet apart, also N 40° E and N 45° W. The physical tests on this stone are given in chapter XXVI.

Microscopical Structure. Mr. S. L. Powell makes the following report on a thin section of this sandstone: (see 6, plate XX).

"The rock is essentially a quartz sandstone composed of grains of quartz which are colorless and transparent, except for the clouding due to the many liquid inclusions or empty cavities. The rock has undergone crushing and recrystallization as shown by the undulatory extinction of the quartz

grains, as well as by the crushed and recemented grains of quartz and feldspar which are occasionally present.

"The quartz grains previous to cementation were moderately well rounded. They vary in shape, however, from round to angular and rhomboidal forms with edges and angles rounded off by erosion. As the cement is largely silica, some of the grains on freshly broken surfaces will show sharp angular points and edges. Many of the grains exhibit secondary enlargement by silica and frequently there are aggregates of small grains and crushed fragments completely intergrown with silica.

"Part of the cementing material is oxide of iron, and a number of the interspaces are filled with an opaque material, the exact nature of which could not be determined. The grains vary in size from a small fraction to 0.9 millimeter in greatest diameter. From a number of measurements made, the diameter of the average grains is 0.4 millimeter. As the interstices between the grains are not completely filled, the rock is somewhat porous."

Chemical Composition. An average lot of this stone was sent to the Survey laboratory, and the following analysis made:

	Per cent.
Silica and insoluble	97.19
Iron and alumina	2.14
Lime oxide	Trace
Magnesium oxide	0.04
Moisture and loss	0.59

This analysis shows a very pure silica rock.

MORGANTOWN SANDSTONE.

Dr. I. C. White in Volume II (p. 250) describes this sandstone as follows:

"At a few feet below the Clarksburg limestone, and separated from it by soft shales, there occurs another of the great sandstone horizons of the Conemaugh series. This stratum was named by Dr. John J. Stevenson from its fine exposures in the vicinity of Morgantown, Monongalia County,

where it was once extensively quarried and used in the construction of the State University buildings and other structures. At this typical locality the top of the sandstone lies a little more than 200 feet below the Pittsburg coal, and the seam has a thickness of twenty-five feet. It has usually a yellowish gray cast, and splits readily into building blocks of any desired size. The rock contains much feldspathic material, and occasionally some lime, and in weathering the rock changes from a bluish gray cast to a dirty brown, and frequently decomposes readily, so that as a building stone for exposed surfaces, it is not a success, some of the stone work at the State University in Morgantown having disintegrated badly within a period of only twenty-five years.

Several of the locks along the Monongahela river, between Morgantown and Pittsburg, have been constructed of this stone, and the disintegration of the lock walls is a constant source of expense.

"This sandstone is one of the most persistent members of the Conemaugh series, and usually forms a line of cliffs or steep bluffs wherever its outcrop extends. Although the stratum is usually only twenty-five or thirty feet thick, yet occasionally, as on Crooked run in Monongalia County, near the West Virginia-Pennsylvania line, it thickens up to one hundred feet in a solid and massive wall.

"Through Monongalia, Marion, Tyler, Preston, Barbour, Upshur, Lewis, Braxton, Clay, Kanawha, Putnam, Mason, Cabell and Wayne, this stratum can be traced from the Pennsylvania line on the north to the Kentucky, boundary on the southwest. It is well exposed along the Ohio river in the region of Huntington, where it makes cliffs fifty to sixty feet high along the hills back from the river valley. It is also conspicuous in cliffs along the Guyandotte, Mud, and Coal rivers, as well as along the Great Kanawha, where it has been frequently quarried and used in building the locks below Charleston."

Bennett Quarry at Huntington, Cabell County.

The Bennett sandstone quarry is located two miles southwest of the city of Huntington on 16th street beyond the plant of the

Plate XIX. Donlan Quarry in Connellsville Sandstone at Weston. Lewis County.

Ohio Clay Shingle Co. It is worked only on a small scale. The floor of the quarry is about 70 feet above the Ames fossiliferous shale and limestone, so the rock would be the Morgantown sandstone.

Quarry. The sandstone is mostly brown or buff in color, and is quarried in blocks of good size. A section shows,

	Feet.
Shales and clay cover	3
Shaly sandstone	4
Solid ledge sandstone, buff	15

Gassaway Development Company Quarries, Braxton County.

The Gassaway Development Company owns two quarries one-half mile southeast of the town of Gassaway which is located on the Coal and Coke railroad. These quarries are worked by various stone contractors who supply the stone for the local trade. The stone has a greenish brown color, mostly fine grained with some white mica irregularly distributed through it, and a few of the ledges show a coarse grained texture. The floor of the quarry is 290 feet above the railroad track at the station, and the stone was opened four years ago when the town was started.

The geological horizon appears to be the Morgantown as shown by the section below the McCale quarry given under the next quarry description.

Quarry. The Duckworth quarry of this company has a north and south face 50 to 60 feet long and is worked back to the east about 30 feet. A section of this quarry shows,

	Feet.
Red clay and sandstone boulders	4
Broken sandstone	2
Buff or greenish sandstone	5
Irregular seam of broken sandstone	2
Buff or greenish sandstone	8
Sandstone with irregular top surface	4

The joint planes run N 30° E and N 60° W, with a few N 20 E. Some of the planes show a curved surface. Very little powder is used, and the stone is worked by wedges. Niggerheads occur in the quarry face, and are 6 to 8 feet in diameter. The

next quarry to the north shows similar character and structure. The physical tests of this stone are given in Chapter XXVI.

Shade and McCale Quarry at Gassaway.

This quarry is located to the northeast of the last group of quarries and over the hill, but at nearly the same level. The stone has a coarse grained texture with conglomerate streaks here and there. In color it is green to a greenish gray, and when fresh gives to buildings a decidedly green tone. It was used in the Catholic church, also the Presbyterian church at Gassaway and in foundations and trimmings of a number of buildings. Some of the ledges show a banded or foliated structure, and flat shale or clay inclusions dot the surface of some of the blocks. The green color is very uniform but in weathered portions of the quarry shows a yellowish gray to almost buff color, thus throwing doubt on the durability of the color. The stone has been used too short a period of time to judge of the permanency of the color.

Quarry. The face of the quarry follows a jointing plane N 30° E and is 65 feet long, and worked back to northwest 30 to 40 feet. A section at center of quarry shows,

	Feet.
Red earth	3
Buff shales	6
Buff shales solid ledge	3
Green sandstone ledge	3
Green sandstone ledge	8

The joint planes run N 55° to 60° W and N 30° E.

At the south end of the quarry the following section was measured:

	Feet.	Inches.
Red clay	4	
Shales	3	
Sandstone ledge	10	
Sandstone ledge	4	
Seam of clay	0	2
Sandstone (to floor of quarry)	4	
Sandstone	2	
White pebble layer	0	4
Sandstone	6	
Sandstone ledge	1	6
Sandstone ledge	3	
Thickness	38	

The joint planes here run N 50° W and N 15° E.

The following section was measured from top of hill above the McCale quarry to the town level, but exposures were poor on account of wash and slip of the hill:

Top of hill.	Feet.
Red and buff shales	18
Shaly sandstone	5
Sandstone at quarry	31
Red shales with shaly sandstone ledges	90
Limestone, brecciated and nodular	2
Red and buff shales	90
Shales, soil and blocks of sandstone	80
Interval to railroad track	28

Across the river and level with the railroad track is a massive gray sandstone which is probably the Mahoning sandstone and the quarry sandstone above the group of red shales of the Conemaugh series would be at the horizon of the Morgantown sandstone.

Zevely Quarry at Morgantown, Monongalia County.

Zevely and Casto have operated a sandstone quarry for several years at the northeast edge of Morgantown near the top of the Front street hill. This quarry furnished the stone for many of the city buildings, for the old buildings of the University, and is the type locality of the Morgantown Sandstone. The floor of the quarry is a short distance above the Elk Lick coal, and 225 feet below the Pittsburg coal. The stone is gray or blue in color, fine grained with small round quartz grains. It is strongly banded or foliated with mica flakes, and weathers to a darker gray and finally to a buff color. The buff stone in the quarry has coarser grain than the blue, also brown and red iron spots.

Quarry. The floor of the quarry is 18 feet lower than the county road. The face runs northeast-southwest at an angle of 50 degrees. It is 100 feet long and worked back 30 to 40 feet almost to the county road line. A section of the quarry shows,

	Feet.	Inches.
Laminated buff shales	8	
Buff sandstone	2	
Shales	3	
Blue and buff sandstone	5	10
Blue or gray sandstone	2	6
Blue sandstone	2	

The buff and blue colors are intermingled to some extent in certain ledges. A blue ledge traced a short distance sometimes changes to a buff. At the south end of the quarry most of the stone is buff or brown in color. The main joint planes run N. 50° E and N 60° to 70° W, also a few N 20° E.

Gaston Quarry at Morgantown.

Mr. Wm. Gaston has operated for six years a quarry a short distance toward town from the Zevely quarry. The stone has been used in Morgantown for foundations and trimmings, and is at the same geological horizon as the Zevely stone. This stone in unweathered blocks has a light gray or bluish gray color. It is an aggregate of rounded quartz grains, the interspaces filled with gray material. It is fine grained and compact. The brown or buff stone in the same quarry has a similar structure to the blue, but contains yellow and brown spots of iron oxide. Mica is abundant and the stone is banded or foliated. The stone splits readily along the foliation planes, and in some of the ledges the bands are irregular and cross bedded.

Quarry. The floor of the quarry is about 200 feet above the Monongahela river. The face runs north and south, 150 feet in length, and it is worked to the east 30 to 60 feet. Ten to twelve perch are quarried daily employing three to four men in the working season. A section of the quarry shows,

	Feet.
Shales, cover	12
Hard sandstone	2
Blue sandstone	11
Sandstone, blue and buff	8
Blue sandstone (not quarried)	4

The two foot layer of sandstone near the top of the quarry has a reddish brown color, and is very hard and close grained. It is sometimes called the niggerhead ledge, and the quartz grains

appear to be cemented by silica, which fills the interspaces. It is not used, but thrown aside in the work. This ledge is best seen at the south end of the quarry and has apparently disappeared in the main quarry.

The joint planes run N 10° E and N 10° W, also north and south. One plane was observed N 50° W and some of the planes are coated with calcite layers. The physical tests on this stone are given in Chapter XXVI.

Microscopical Structure. Mr. S. L. Powell makes the following report on microscopical examination of a thin section of the sandstone from the Gaston quarry (see 4, plate XX):

"This section shows the rock to have been originally a sand composed of quartz, feldspar, mica (biotite), and kaolin, the quartz largely predominating. Altered feldspars are abundant, but fresh ones are of rare occurrence. They are, as a rule, much altered, either kaolinized or completely changed to a mixture of minerals known as saussurite. There is developed in addition some chlorite, calcite, and oxide of iron. But little of the original biotite remains, and that is very much bleached, and is frequently represented by strings or bands of iron oxide. There is present also a cherty opaque substance, which frequently fills the interspaces not previously occupied by the alteration products of the feldspar.

"The chief cement is silica which has enlarged and united the quartz grains. The other cementing substance is the combination of secondary minerals; calcite, chlorite, muscovite, and iron oxide, which have developed in the interspaces between the grains. The grains vary much in shape from round to irregularly elongated and angular forms. In size they vary from 0.1 to 0.8 millimeter and will average 0.4 millimeter."

ST. ALBANS SANDSTONE.

Sattes Quarry at Sattes (St. Albans), Kanawha County.

On the north side of the Kanawha river at Sattes opposite St. Albans, and 12 miles west of Charleston, Mr. F. A Sattes operates a sandstone quarry for building stone and grindstones. The adjacent quarry now abandoned, furnished stone for the

Kanawha river locks and for bridges on the Kanawha and Michigan railroad.

The Pittsburg coal comes in the top of the hills back of St. Albans, and the interval with allowance for dip would place this sandstone somewhere near the horizon of the Morgantown sandstone; but as there are no key rocks exposed in the hill near this quarry, its place is somewhat doubtful. Dr. I. C. White has recently named the sandstone across the river at St. Albans, the St. Albans Sandstone, and the Sattes quarry would come at this horizon.

The rock is blue, also light brown or buff in color. It contains small grains of quartz and has a fine granular texture. In places shale streaks give it a rough appearance, and included clay masses give some of the stone a spotted appearance. At the level of the quarry floor is a building containing the grindstone sawing and turning machinery. Both blue and buff stone are used for grindstones which are here usually made 5½ feet in diameter with a 10 inch face, and are claimed to be very satisfactory in use, but this branch of the industry is small. The building stone is shipped to Charleston and other points along the Kanawha and Michigan railroad.

Quarry. The floor of the quarry is 90 feet above the K. & M. railroad track. The face runs N 70° W and the old working face is 360 to 400 feet long, while the face of the present working quarry is 60 feet long and worked back 30 to 40 feet.

The shale roof breaks down into the sandstone, in places cutting it out. At center of the quarry the shale is thus 30 to 40 feet thick and lenses of shale separate ledges of the stone while further along the shale is replaced by sandstone. The shale cover in other parts of the quarry is only 10 to 12 feet. As followed to the east, the shale dips down cutting out a large portion of the sandstone. A section of the quarry at the west end shows,

	Feet.
Red soil	2
Red and blue shales	12
Brown and blue sandstone	9
Brown sandstone (Ripple marked)	7
Brown or buff sandstone	8
Buff sandstone	5
Blue fire clay	4

The underlying blue fire clay contains small nodules of blue limestone through it, and the bedding planes dip strongly to the east. The loading track is 25 feet below the floor of the quarry, and from this level to the quarry is a mass of red and buff shales. The joint planes run N. 60° to 70° W and N 25° E. Physical tests on this stone are given in Chapter XXVI.

Old Quarry. Just east of the above quarry is an old quarry now abandoned. The stone is blue and buff to brown in color, and the quarry face runs with one of the joint planes N 30° E. Some of the rock is foliated with mica planes, and some of the ledges contain poor impressions of plant stems. The rock is hard and even the ledges containing the shale streaks seem to withstand weathering action, though they have acquired rough surfaces, being pitted and furrowed. The stone appears to split readily and very large blocks are piled at the side of the quarry, which furnished stone used especially for bridge piers. A section of this old quarry shows the following structure:

	Feet.	Inches.
Red shales, finely laminated	20	
Shaly sandstone	0	10
Buff sandstone	3	
Buff shale	0	2
Blue sandstone ledge	8	
Blue sandstone ledge	2	
Shales	0	10
Blue sandstone, with shale spots	4	

The joint planes run N 30° E, also due east and west.

Chemical Composition. An average lot of stone from the present working quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	88.18
Iron and alumina	8.47
Lime oxide	0.28
Magnesium oxide	0.80
Moisture and loss	2.48

This analysis shows rather large alumina content, partly from the cement of the sandstone, the feldspars, but probably more from the included clay concretions.

Microscopical Structure. Mr. S. L. Powell's report on a thin section of this sandstone is as follows: "The section shows

the rock to have been derived from an intimate mixture of round to angular grains of quartz, feldspar, and kaolin, together with some argillaceous matter. Secondary silica is not so abundantly developed, but is sufficient to firmly unite the quartz grains.

"The feldspars are mostly altered, giving rise to poikilitic (variegated) areas of secondary minerals. as well as to larger surfaces of calcite,, chlorite, and muscovite. There is a considerable amount or iron oxide present which adds its quota to the cement. The cement or bond of the rock is, therefore, a combination of silica and secondary minerals, which with the arigillaceous matter fill the interspaces between the grains. The section was badly broken, only fragments remaining, and some of the interstitial matter is lost."

SALTZBURG SANDSTONE.

The Pittsburg red shales are sometimes replaced in part by a massive sandstone, named by Dr. J. J. Stevenson, the Saltzburg sandstone from its occurrence with a thickness of 100 feet near Saltzburg, Westmoreland county, Pennsylvania. Dr. I. C. White states in volume II (p. 265) that this sandstone is generally present and quite massive in the tier of counties extending from Braxton along Elk to the Great Kanawha and beyond. It is also well developed in Brooke county in the northern Pan Handle near Colliers, and also in vicinity of Wellsburg.

Sandstone Quarry Near Wellsburg, Brooke County.

Just south of Wellsburg where the Bethany turnpike passes under the trolley road, a quarry has been opened and worked for many years to supply a small local demand. This sandstone is 75 feet below the Ames limestone and 305 feet below the Pittsburg coal. It is overlaid by the Pittsburg red shales, and represents the Saltzburg sandstone.

Quarry. The quarry face is 60 to 75 feet long and worked back 25 to 30 feet. The stone is buff or brown in color, fairly coarse grained in texture, but easily worked. A section of the quarry shows,

	Feet.
Shales and shaly sandstone	12
Buff sandstone	15

Gocella Quarry at Albright, Preston County.

Mr. G. A. Gocella of Falls Creek, Pa., opened a sandstone quarry in the summer of 1907 at Albright, a station on the Morgantown and Kingwood railroad three miles east of Kingwood. The stone was used on the abutments of the new B. & O. bridge near Rowlesburg, and has been shipped to other points for building stone. A quarry in the same sandstone was opened by Zevely and Casto one mile west of Kingwood, and the rock from this quarry is used mainly for curbing at Morgantown.

Some of the stone is gray to white in color and fine grained in texture. Other portions are mottled with brown iron spots, and some ledges are yellow to light brown in color, dotted with iron spots. Various colors are to be found, but the main rock is the mottled gray or brown rock. In 1907, 36 to 40 men were employed and five cars loaded daily.

The quarry is near the center of the large syncline and the Upper Freeport coal goes under Cheat river three-fourths mile west at a level of 216 feet below the quarry. The Bakerstown coal was formerly mined on a small scale on the Kingwood pike at a level 30 to 40 feet below the base of this sandstone, and it therefore represents the Saltzburg sandstone.

Quarry. The quarry is worked with a face 300 feet long and back 15 to 20 feet. The base of the rock is not reached, and the blocks which have rolled down the hill are also worked. The stone is in two ledges,

	Feet.
Cover	1
Sandstone ledge	8
Sandstone ledge	10

The joint planes run N 50° W and N 20° E, with a few N 5° E.

The physical tests on this stone are given in Chapter XXVI.

BUFFALO SANDSTONE.

Just below the Upper Cambridge or Pine Creek limestone of the Conemaugh series, there often occurs a massive, sandstone named by Dr. I. C. White, the Buffalo Sandstone from its great development along Buffalo Creek in Butler county, Pennsylvania. At this locality, it is 50 feet thick with its top 175 feet above the base of the Conemaugh.

According to Dr. I. C. White (Vol. II, p. 274) this sandstone is exposed in a massive stratum along Deckers Creek at Morgantown; in the vicinity of Grafton where it makes great cliffs along the bluffs 50 to 100 feet above the B. & O. railroad track, also south along the Valley river to Phillipi in Barbour county. It forms cliffs along the Buckhannon river, and along Elk river near Sutton and south to Charleston. "It extends southwestward from the Great Kanawha across Lincoln, Boone, Cabell and Wayne counties to the Kentucky line, making great cliffs along Big and Little Coal, Mud, Guyandot, Twelve Pole, and the Big Sandy rivers.

The stratum is frequently very pebbly, and occasionally the disintegrated matrix leaves a thick bed of rounded quartz gravel, some an inch or more in diameter, on the summits of many, ridges, between the Great Kanawha and Big Sandy rivers."

Poling Quarry at Phillipi, Barbour County.

A. W. Poling and Son opened some years ago a quarry near the top of the hill one mile and a half southwest of Phillipi, where a very heavy ledge of sandstone outcrops. Later they opened the stone higher on the hill on the land owned by Hon. A. G. Dayton. For the past two or three years only the upper quarry has been used.

The old quarry now practically abandoned was opened on the corner of a hill and worked on both sides of this hill with a long exposed face. The bottom of the quarry is 150 feet above the old coal mines at the Upper Kittanning horizon, so this outcrop would be the Buffalo Sandstone. The stone is very coarse with quartz pebbles through it forming conglomerate layers. In

the lower ledges, it is a very coarse pebble rock. The unweathered sandstone has a light gray to white color, with some bluish gray ledges. It weathers to a brown or buff. In other ledges there is a variety of colors and some cross bedding structure. In the upper quarry, the stone has a yellowish buff and yellowish white color, with round white quartz crystals through it. Iron spots in some ledges give a mottled brownish white color.

Quarry. The face of the lower quarry is almost unbroken by horizontal joint planes, but the stone readily splits into beds or layers. The face is 18 to 25 feet in height, and was worked in benches with about four foot courses. On the southwest side of the hill, two additional ledges, 6 and 5 feet thick come above the main face, giving here a total height of 30 feet. The following section was measured on the side of the hill facing town:

	Feet.
Shaly sandstone and clay................	4
Fine grained buff sandstone..............	8
Pebbly, very coarse grained sandstone.....	10

The main joint plane makes the face of the quarry and runs N 80° E; other joints run nearly north and south. One large plane of fracture was observed running N 60° W. Two bed planes are visible, one five feet from the top and the other twelve feet from the bottom. The physical tests on the stone from the upper quarry are given in Chapter XXVI.

Ramsey and Stark Quarry at Grafton, Taylor County.

Ramsey and Stark opened a quarry in March, 1907, on the Isaac Evans farm just across the county bridge from the first ward of Grafton, or Fetterman, a mile and half northwest from the Grafton railroad station. They employed in 1907, 12 men and quarried 20 perch daily during the working season. The floor of the quarry is 36 feet above the bridge or 50 feet above the Tygart river.

The horizon of this stone is the Buffalo Sandstone. It is a blue, fine grained rock, with black and white mica scattered through giving the so-called pepper and salt appearance. It shows

lamination or banding in most of the ledges, and some of the stone has a coarser grained texture with larger quartz crystals.

Quarry. This sandstone outcrops for a half to three-fourth mile along the hill at this locality and has been opened at a number of places. The present quarry has been worked along a face of 500 feet north and south, and shows a height of 30 to 40 feet of which 16 feet are now worked. A section of the quarry shows,

	Feet.
Shales	40
Shaly sandstone	3
Blue sandstone ledge	8
Blue sandstone ledge	8

On account of the sloping hillside, it is not necessary at the present time to make a very heavy stripping to uncover the stone, and the length of face will postpone the time of this increased cost of working. The upper 12 feet of the quarry is softer and finer grained than the lower 4 feet. Nearly all of the stone is foliated or banded parallel to the bedding planes, and makes a very pleasing trimming stone on account of its color and texture.

The joint planes run N 20° E, N 70° W, and a few N 10° E.

Distillery Quarry at Grafton.

Ramsey and Stark formerly worked a quarry up a ravine to the east of Fetterman near the old distillery, and about a half mile from the present quarry. The stone is at the same geological horizon and is similar in appearance to the stone at the present working quarry. A section of this quarry, not now in use, shows,

	Feet
Shaly buff sandstone	6
Blue sandstone ledge	5
Blue sandstone ledge	4
Blue sandstone ledge	3

Willhide Quarry at Grafton.

Korte and Barlow have operated a quarry on the W. A. Willhide land one mile west of Grafton near the Baltimore and Ohio railroad to Clarksburg. The stone is hauled to town and used as

Plate XX.—Thin Sections of Sandstones, Magnified 20 Times.
1. Alderson quarry. 3. Casparis quarry. 5. Briscoe quarry
2. Naughton quarry. 4. Gaston quarry. 6. Cox quarry.

building stone. The quarry is only worked on a small scale a portion of the season, but it is a popular building stone at this place. The horizon is the same as at the other Grafton quarries, the Buffalo Sandstone.

The weathered stone is brown or buff in color, and the fresh rock bluish gray to green. It is banded with mica planes, but these run somewhat uneven causing the stone to split irregular in many of the ledges. The mica planes are also somewhat inclined giving a cross bedded appearance. Blocks of blue stone of good size for building or trimming can be obtained, but care must be used to secure smooth blocks on account of the irregular fracture.

Quarry. The face of the quarry is determined by one of the prominent jointing planes N 25° to 30° E., and is 50 feet long, and worked to the west 10 to 12 feet. A section of the quarry shows,

	Feet.
Soil and shale cover	2
Shaly sandstone .....3 to	6
Shaly blue sandstone, somewhat cross bedded	3
Blue to greenish sandstone, foliated	2
Blue foliated sandstone	9
Blue sandstone	12

The 9-foot ledge of blue foliated sandstone shows an upper five feet of strongly black banded stone; and the bands are quite irregular and cross bedded. The lower four feet has a blue and buff color, with a distinct bedding plane between it and the lower solid ledge of 12 feet.

The joint planes run N 20° to 30° E and N 20° W. There are several planes N 80° E and a few N 60° W. Some of the joint planes are coated with a lime scale.

Stozenfels Quarry at Grafton.

Chas. Stozenfels owns a sandstone quarry located three-fourth mile east of the B. & O. station at Grafton, and at the eastern edge of the town. The quarry has been operated for the past two years by J. W. Drennan & Co. The floor of the quarry is 140 feet above the river and the Upper Freeport coal is just

under the river at this place. The interval would place the rock at the horizon of the Buffalo Sandstone.

The Stozenfels sandstone has recently been used in the piers of the new county bridge across the Valley river at the south edge of Grafton, and is used for building stone in town. The old quarries just east of the present one were worked years ago for bridge stone for the B. & O. bridges from Grafton to Parkersburg. The piers of the large bridge and approaches at the Ohio river in Parkersburg came from these old quarries which have been abandoned for many years.

The sandstone is coarse grained, white to gray in color when freshly quarried, and weathers to a reddish gray or brown. It is dotted with small red iron spots and has a few small scales of white mica. Some of the ledges are fine grained almost quartzitic, while others have a sugary texture.

Quarry. The quarry face runs northeast-southwest at an angle of about 45 degrees, 150 feet long, and worked back about 20 feet. The quarry shows the following section:

	Feet.
Soil and clay	3
Hard, light buff or brown sandstone	6
Sandstone ledge	24

The joint planes run N 50° W, N 30° E, also a few N 45° W. The northeast joints are two to six feet apart. The physical tests on this sandstone are given in Chapter XXVI.

Chemical Composition. An average lot of the sandstone from this quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	97.83
Iron and alumina	1.76
Lime oxide	Trace
Magnesium oxide	Trace
Moisture and loss	0.19

This analysis shows a very pure sandstone unusually low in impurities. The low percentage of iron and alumina would indicate the cement of the rock was silica, representing a very durable sandstone.

Microscopical Structure. Mr. S. L. Powell makes the following report of his study on a thin section of this sandstone:

"It is essentially a quartz sandstone with a few scattered feldspars, and flakes of muscovite and kaolin. There is a considerable amount of yellow or rusty oxide of iron disseminated through the rock mass, but it forms no part of the cement.

"The cement is silica and it is abundant. The quartz grains have been enlarged and extended into complete interlocking masses. Many of the grains have developed crystal forms, the facets of which appear as brilliant points in the hard specimen. The few feldspars present are very much altered. Their decomposition has in all probability given rise to the small white flakes of kaolin scattered through the rock. The average diameter of the quartz grains is about 0.5 millimeter."

Keane Quarry at Grafton.

John M. Keane has worked a sandstone quarry, at east edge of the city of Grafton across the river and high on the hill for a number of years though at the present time it is not in use. The floor of the quarry is 30 feet higher than the floor of the Stozenfels quarry, and 172 feet above the river. The stone was hauled in wagons down a steep hillside road to town where it was used as building stone. Its horizon is the Buffalo Sandstone. Some of the ledges have a gray to creamy white color, while the rest has a blue or buff color. It contains considerable mica and is banded.

Quarry. The face of the quarry runs N 40° W 80 feet long, and worked back 30 to 40 feet. A section of the quarry shows,

	Feet.	Inches.
Soil and reddish brown shales	2 to 10	
Shaly sandstone	4	
Blue sandstone	10	
Fine flaky shales or clay	0	2 to 18
Light gray coarse sandstone, foliated	10	
Brown sandstone, foliated	6	

The 10 foot ledge of light gray coarse sandstone is banded or foliated, and the planes dip to the southeast at a high angle, giv-

ing the appearance of cross bedding, but the bed planes are nearly horizontal. The 6 foot ledge of brown sandstone has a pronounced foliation.

At the ends of the quarry on weathered outcrop the stone breaks irregularly and shows more ledges. At the east end, the following section was measured:

	Feet.
Sandstone, badly broken and seamed......	12
Sandstone ledge	3
Sandstone ledge	3
Sandstone ledge	3
Sandstone ledge	4
Shales.	

The joint planes run N 80° W, N 35° W, N 40° W, and N 10° E.

Christian Quarry at Morgantown, Monongalia County.

Mr. David Breakiron has been operating for a few years a small quarry on the Christian land near the river lock above the city of Morgantown and on the west bank of the Monongahela River. The stone has been used for foundations and trimmings of buildings in Morgantown, and the waste rock used for road material.

This sandstone is found 50 to 60 feet above the river level and above the Mahoning horizon, so is the Buffalo Sandstone. The blue stone is composed of small rounded quartz grains, fairly compact in texture, and the stone is strongly banded or foliated, with abundant white mica flakes and some black mica. The buff stone has a similar texture, though in some ledges is coarser in grain, and contains numerous yellow and red iron spots. Occasionally the blue and buff colors are seen in the same block with a sharp line of contact between the colors. On weathering, the stone becomes a darker gray or darker buff to brown color.

Quarry. The face of the quarry runs N 40° E, 60 feet in length, and worked back 20 feet into the hill. The length of face could be extended 200 to 300 feet. The lower portion of the quarry pitches north 20 degrees, while the upper layers are nearly

horizontal. The structure is thus cross bedded. A section of the quarry shows,

	Feet.
Chocolate brown shales	8 to 10
Shaly sandstone	2
Buff and blue sandstone	3
Blue sandstone ledge	2
Blue sandstone ledge	2
Blue sandstone ledge	1
Blue foliated sandstone	4
Buff and blue sandstone	2½
Blue shelly sandstone	1
Blue foliated sandstone	6

The blue sandstone is often brown on outside, but when the blocks are broken they show the blue color. Some of the ledges thin out as followed to the north, and they vary in thickness in different parts of the quarry. The foliated structure causes the stone to split readily leaving smooth surfaces.

The joint planes run N 30° W and N 40° E, with a few N 60° W. Physical tests on this stone from a quarry just above on the river bank are given in Chapter XXVI.

Chemical Composition. An average lot of stone from the Christian quarry was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	93.59
Iron and alumina	2.98
Lime oxide	0.95
Magnesium oxide	0.37
Moisture and loss	2.22

The stone shows a lower percentage of silica and higher iron and alumina than the Stozenfels sandstone at Grafton, and it is quite different in texture.

Keck Quarry at Morgantown.

On the land of L. V. Keck across the Monongahela river bridge in west Morgantown, a quarry has long been used for a local supply of building stone. It was worked back into the hill until the heavy cover prevented profitable work and in 1908 was abandoned. The horizon is the Buffalo Sandstone. The rock is

blue or gray in color, foliated and splits easily along the foliation planes which are parallel to the bed. It glistens with mica flakes and the color appears to be quite durable, though in quarry exposure it weathers to a darker gray and in places to a buff or brown.

On account of its bright color, it has proved a popular stone at Morgantown. It was used in the new Methodist Church, the President's house and business blocks. The stone has a brighter color and is apparently as durable as the Cleveland stone used in many buildings in this state (see plate XXI).

Quarry. The floor of the quarry is 50 to 60 feet above the river. The face was worked northeast-southwest, about 150 feet long, and worked back 25 to 40 feet. A section of the quarry shows,

	Feet.
Red shales	30 to 40
Hard sandstone	2
Gray or blue sandstone, foliated	22

Microscopical Structure. Mr. S. L. Powell makes the following report on two thin sections of this sandstone, cut at right angles to each other; one with the bedding plane and the other across it:

"The sections show this sandstone to be composed of grains of quartz, feldspar, mica, kaolin, and a few grains of zircon; together with a number of minerals of secondary development, as chlorite, calcite, muscovite, kaolin, etc.

"Some of the quartz grains were well rounded as may be seen from the rim of iron surrounding the grains previous to its enlargement by silica. The border of secondary quartz outside of the coating of iron oxide orients with the original grain. In one instance this was observed to restore the crystal outline, terminating the form with the pyramid. Many of the grains have undergone crushing and recementation, and others show an undulatory extinction, the result of strain. The secondary growth of silica has extended the grains until they mutually interlock, and in the majority of cases obliterate their original outline. The amount of enlargement may, however, be determined by the manner of interlocking and the delicate shading or fading out, observed between crossed nicols in the microscope.

"The feldspars are with few exceptions much altered, some of them completely broken down into a fine grained or fibrous intricate mosaic of alteration products, as silica, calcite, chlorite, muscovite, and kaolin, often filling the interstitial areas. In some areas the interstitial matter is large muscovite and calcite. The original biotite is much altered, mostly to oxide of iron and kaolin. The cement is silica, together with secondary siliceous minerals and some oxide of iron. The average diameter of the quartz grains is about 0.5 millimeter."

Simmons Quarry at Frametown, Braxton County.

Frametown is a small station on the Coal and Coke railroad, ten miles below Gassaway on the Elk river. Mr. Simmons of Gassaway opened a quarry on opposite side of the river from the railroad station, a few years ago. It has been worked on a small scale. The floor of the quarry is 100 feet above the railroad track level or 917 feet above the sea level, and 130 feet above the river.

The stone is coarse grained in texture with clear quartz grains. It has a buff or yellowish brown color. Dr. I. C. White measured a section about three miles below this quarry nearly along the line of strike of the formations, (see Vol. II-A, p. 566), which would place this sandstone at the Buffalo-Mahoning horizon. In this area the two sandstones are united.

Quarry. The face of the quarry runs N 50° E, 40 to 50 feet long, and worked to northwest about 15 feet. A section of the quarry shows,

	Feet.
Soil	3
Broken sandstone	3
Sandstone	8

The upper 30 inches of the eight foot face is very coarse sandstone while the lower portion is somewhat finer grained.

A short distance to the south is a second quarry 60 feet long and 25 feet wide which shows the following ledges:

	Feet.
Soil	1
Flag sandstone	4
Sandstone	6

The face of this quarry runs N 80° W and is worked to the north. The joint planes run N 50° E and N 20° W. The sandstone continues for at least 50 feet below quarry level in form of large boulders apparently in place. The physical tests on this sandstone are given in Chapter XXVI.

MAHONING SANDSTONE.

At the base of the Conemaugh series is a massive sandstone stratum, 80 to 100 feet thick, frequently separated into two sandstones. Dr. I. C. White in Volume II (p. 305) gives the following description of this formation: "Being hard, frequently pebbly, and the sand grains cemented largely by peroxide of iron and silica, these sandstone beds often cap the high ridges and peaks with an almost indestructible roof, and thus preserve the underlying softer rocks from destruction.

"The massive sandstone beds are generally traversed by two systems of jointing planes, and hence large blocks of these sandstones frequently descend into the valley or litter up the slopes wherever they can find a lodgment.

"These sandstones split readily into blocks of desirable size, and have been frequently quarried for building and bridge masonry. The stone in the Capitol at Charleston, the Court House at Buckhannon, and many other structures throughout the state, come from rocks of this stage. Occasionally either from the presence of pyrites, or other easily destroyed constituents, these sandstones break down and weather into all kinds of shapes, a fine example of which may be seen in Monongalia County, one-half mile east of the Monongahela river, along the banks of Booth's Creek, at the locality known as 'Raven Rocks.' There the Upper and Lower Mahoning beds, having united into one mass, make a cliff nearly one hundred feet high, the face of which is weathered into many fantastic shapes and pitted with holes and cavities of every description. The Upper Mahoning is generally the more massive member, and the better quarry rock of the two.

"The name Charleston sandstone was given to these beds, and the overlying Buffalo sandstone, by the U. S. G. Survey in its Charleston Folio, but as the name Mahoning, given by the

First Geological Survey of Pennsylvania from the Mahoning river in that state, has priority, the new one cannot be adopted without violating one of the fundamental laws of nomenclature."

Sims and Company Quarry at Yates, Taylor County.

At Yates four miles up the Valley river from Grafton at the side of the Belington branch of the Baltimore and Ohio railroad, a quarry was opened eight years ago to supply stone for bridge piers on the railroad. This stone was used on the B. & O. main line bridge at Grafton. After the completion of the railroad lines, the quarry was abandoned. During 1907 this quarry has been re-opened by Sims & Co., railroad contractors, and a large amount of stone was taken out for their work of double tracking the eastern portion of the B. & O. railroad. The stone from this quarry is regarded as one of the best bridge stones on the line and the contractors claim that after testing various quarries, they decided this was the best stone available for their work.

The Yates quarry sandstone is 25 to 30 feet above the river and comes below the Buffalo sandstone quarried at Grafton, and hence is most probably the Mahoning Sandstone. The stone is very coarse grained in texture, much of it being a pebbly rock or conglomerate. In the coarser conglomerate, the quartz pebbles are 1/8 to 1/4 inch in size, loosely cemented. Its color varies from a white to a buff, and the stone is very hard, breaking with an irregular fracture.

Quarry. The floor of the quarry is 8 feet above the railroad track. The face runs north and south, about 120 feet long, and worked to the east 40 feet wide. A section of the quarry shows,

	Feet.
Sandstone boulders and soil	4
Coarse granular sandstone	9
Conglomerate	2

At the north end of the quarry the conglomerate is eight feet thick with three feet of coarse grained sandstone above. The floor of the quarry is a conglomerate. The joint planes run north and south, east and west, also N 15° E. The last set of planes form smooth faces and are quite numerous.

CHAPTER XXIII.

THE SANDSTONES OF THE ALLEGHENY AND POTTSVILLE SERIES.

ALLEGHENY SERIES.

Upper Freeport sandstone.
Lower Freeport sandstone.
Clarion sandstone.

POTTSVILLE SERIES.

Northern Section:
- Homewood sandstone.
- Connoquenessing sandstones.
- Sharon conglomerate.

Southern Section:
- Coalburg sandstone.
- Winifrede sandstones.
- Clinton sandstone.
- Malden sandstone.
- Brownstown sandstone.
- Nuttall sandstone.
- Raleigh sandstones.

ALLEGHENY SERIES.

UPPER FREEPORT SANDSTONE.

Between the upper and lower Freeport coals there often is found a sandstone stratum known as the Upper Freeport Sandstone. Dr. I. C. White states that it is quite prominent in some portions of Pennsylvania, but generally absent in

Ohio, while in West Virginia it sometimes attains a thckness of 75 feet.

Cady and Shield Quarry at Belington, Barbour County.

One mile and a fourth south of Belington at the end of the Coal & Coke Railroad bridge, a quarry was opened to supply stone for the bridge, by Cady and Shield, contractors. After the completion of the bridge, the quarry was abandoned. Across the bridge a quarry was opened on the Henry Monahan farm about the same time. The sandstone appears at be at the horizon of the Upper Freeport Sandstone.

Quarry. The floor of the quarry is level with the Coal and Coke railroad track, and 25 or 30 feet above the Western Marland track below, which is 15 feet above the river.

The stone is a coarse conglomerate with some layers of fine grained white sandstone. It is very hard and has curved iron seams through it. Near the middle of the ledge is a small pebble conglomerate, two or three feet thick. The conglomerate forms lenses and wedge shaped areas in the main sandstone. The cover consists of one or two feet of shales and soil, while the main face of stone is 20 to 25 feet high. The rock is cut by numerous seams or cracks and the main joint planes run N. 30° W and N 75° E.

Woods Quarry at Phillipi, Barbour County.

One mile east of Phillipi on the county road on the Sam V. Woods farm, A. W. Poling and Son have worked a small quarry for use in the town. Across the river from the station a sandstone was worked for stone for the front of the Opera House. This river sandstone comes just over the four foot coal (Upper Kittanning) above the river level, so is the Lower Freeport sandstone.

Above the Woods quarry about 60 feet is the coal locally called the six foot vein representing the Upper Freeport so the sandstone would be the Upper Freeport Sandstone. The color of the stone varies from a white or grayish white to

bluish green and on weathered outcrop shows a buff or brown color. It has a very fine grained texture and the quartz grains canot be seen except under a lens. The stone is very hard and tends to break irregular. Small flakes of white and black mica occur through the rock. A few ledges show a coarser texture with small areas of rounded quartz grains, and have a pronounced sugary or saccharoidal texture.

Quarry. The face of the quarry runs northwest-southeast about 50 feet long and worked to the north 15 feet. The bed planes pitch to the west in part of the quarry and in other places to the east. The floor is 10 feet above the county road level and 30 feet above the creek. A section of the quarry shows,

	Feet.
Soil cover	3
Shaly sandstone	3
Blue, fine grained sandstone..............	6
Blue sandstone	6

The joint planes run N 20° E, N 80° W and N 60° W, the last set determines the direction of the face of the quarry.

Microscopical Structure. A thin section of this sandstone was examined by Mr. S. L. Powell who makes the following report:

"This is a fine grained homogeneous sandstone consisting almost wholly of quartz grains. Under a lens, it is seen to be an aggregate of minute, clear quartz crystals, cemented by silica which has restored to each grain its crystalline outline. Many of these restored crystals possess pyramidal terminations, which give the rock a rough gritty feel. The rock is porous, but has sufficient amount of silica to firmly cement the grains. There is in addition a little iron, sufficient to give much of the stone a slightly yellowish color, and adds its quota to the cement. Occasionally a feldspar is present, but this mineral is not common. The average diameter of the grains is about 0.3 millimeter."

BUFFALO-MAHONING-FREEPORT SANDSTONE.

In the vicinity of Charleston there is a massive sandstone stratum which was named by M. R. Campbell in the Charleston Folio of the U. S. Geological Survey,, the Charleston Sandstone. Campbell in this folio describes the formation as follows: "The Charleston sandstone consists of a series of coarse sandy or conglomerate beds which separate the Kanawha formation from the red and green shales and green sandstones of the formation next above."

Campbell further states: "The Charleston sandstone is made up of a variable number of beds of coarse material separated by shale and coal beds. It is particularly prominent in the river bluffs from Malden to Spring Hill. At Charleston it forms picturesque cliffs, especially on the southwestern side of the river, and it is from this place that it has been named. * * * * At Charleston it is about 300 feet thick, and in the Little Coal river region it presumably in a few places exceeds 250 feet. After passing below water level it seems to be as variable in thickness as it is above."

Dr. I. C. White made the following section at Charleston (Vol. II-A, p. 548):

	Feet.
1. Red marly beds of the Conemaugh	50
2. Sandstone, coarse, brown, pebbly	30
3. Coal 2 feet to	3
4. Concealed	10
5. Sandstone, very massive, pebbly	90
6. Fire clay, massive sandstone and concealed	100
7. Coal, No. 5, blossom	..
8. Concealed	10
9. Sandstone, massive (Roaring Creek) to level C. & O	90
10. Concealed to Kanawha Black Flint near Kanawha river level	30

Dr. I. C. White says of this section (p. 549), "The members of the Charleston section from Nos. 5 to 9, inclusive, make up the Charleston sandstone of Campbell, 250 to 300 feet in thickness, and it contains representatives of the Conemaugh, all of the Allegheny and a portion of the Pottsville, so that except for a local designation where the coals are

mostly absent as along the Coal and Coke railway for a mile or two above Charleston, it is impracticable to use a term which includes so many formations."

The northwest dip would bring the Roaring Creek sandstone below the Elk river at the present working quarries, so that the sandstone there exposed would represent the Freeport, Mahoning and Buffalo horizons and with the absence of coals it is impossible to separate them. It has therefore been considered advisable to write these terms as in the above heading of this section.

Coal and Coke Railroad Quarry at Charleston, Kanawha County.

A large sandstone quarry was opened a number of years ago a short distance up Elk river from Charleston, to supply stone for the locks and dams on the Kanawha river. In April, 1904, the quarry was opened to supply ballast for the railroad, and has been open since that time. It is located at the side of the Coal and Coke railroad track in the Elk river bluff one mile and a half northeast of Charleston, and is operated by the railroad company. Seventy or 80 men are employed and 250 to 300 yards of ballast quarried and crushed daily. At the present time no building stone is quarried.

The floor of the quarry is about 30 feet above Elk river, and a small coal is found near the center of the quarry which is probably one of the Allegheny coals. This sandstone forms the upper portion of the Charleston sandstone of Campbell, or the Buffalo-Mahoning horizon and probably a part of the Freeport.

The stone is rather fine grained, blue to gray in color with mica flakes through it. It breaks readily into blocks and shows foliation in many ledges. These planes are often curved, but the curved lines finally disappear in the solid stone.

Quarry. Plate XXII shows a view from the top of the quarry looking toward the crusher and one side of the quarry with the Elk river and railroad track beyond. The face of the quarry runs northeast-southwest at an angle of nearly 45

Plate XXI.—A.—President's Residence, West Virginia University, Morgantown. Built of Buffalo Sandstone from Keck Quarry.

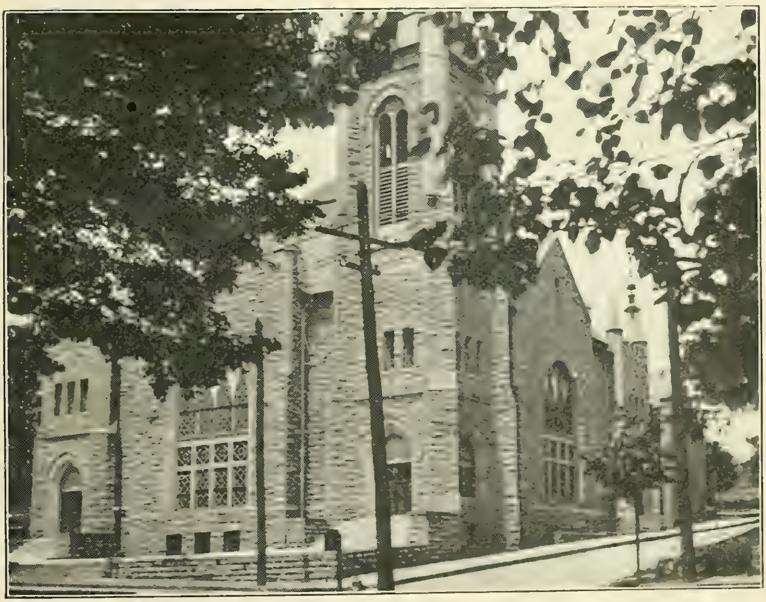

Plate XXI.—B.—Methodist Church at Morgantown. Built of Buffalo Sandstone from Keck Quarry.

degrees. It is 350 to 400 feet long, and worked back 40 to 60 feet. A section of the quarry shows,

	Feet.	Inches.
Shaly sandstone	20	
Sandstone, solid ledge	50	
Dark shale	1	
Sandstone	10	
Coal	0	6
Blue sandstone	80	

Above the top of the quarry the sandstone extends 40 to 50 feet higher, but this portion is not quarried. The physical tests on this sandstone are given in Chapter XXVI.

Chemical Composition. An average lot of this quarry stone was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica	90.41
Alumina	4.47
Iron	1.24
Lime oxide	Trace
Magnesium oxide	0.29
Alkalies	1.14
Loss on ignition	2.45

This analysis shows a considerable percentage of alumina which is probably an important constituent of the cement as well as a component in the feldspar and mica.

Microscopical Structure. Mr. S. L. Powell presents the following report on a thin section of sandstone from the Coal and Coke quarry:

"This sandstone is composed of grains of quartz, feldspar, and mica, with the quartz predominating. The quartz grains vary from a few rounded to sharply angular and broken forms. There has been considerable development of secondary silica which has enlarged and united the quartz grains into large completely interlocking areas. The extended margins also give the grains a rough gritty feel on broken surfaces.

"In the areas where feldspars predominate, secondary silica is less abundant, but in its place occur the secondary minerals, chlorite, muscovite or sericite, and kaolin, also areas

of saussurite largely from the decomposition of feldspar. The section also shows some oxide of iron, probably originating from the decomposition of an iron mica. Vermiculite is beautifully developed in certain areas.

"Feldspar is rather abundant. Some crystals are remarkably fresh and but slightly altered. Some are kaolinized, and others completely altered. The quartz grains show undulatory extinction, and many of them are crushed and broken. They vary in size from a fraction to more than one millimeter in length, and would average about 0.45 millimeter in diameter."

Patrick Ryan Quarry at Charleston.

One mile northeast of Charleston up a ravine a short distance from the Coal and Coke quarry, Mr. Patrick Ryan operates a sandstone quarry opened 20 years ago. Ten men are employed and two or three perch of building stone sent out daily during the working season, also 100 to 200 tons of crushed stone for concrete. Its geological horizon is the same as at the Coal and Coke quarry.

The sandstone is bluish gray in color, foliated with mica flakes. Some of the stone is banded with wavy red lines due to iron stain, giving a variegated color. In other ledges the stone is nearly pink in color, and the calico stone is characterized by irregular wavy bands of yellow and red through a buff or yellowish rock. The stone readily breaks along the mica planes or along the red streaks. The bands are often cross bedded and more or less curved. On account of the number of bands or planes, the stone can be split into blocks of almost any desired thickness, building blocks, curb, or flagging.

Quarry. The face of the quarry runs about 45 degrees northwest, 300 feet long, and worked back 30 to 40 feet. The quarry is located on Coal Branch, and was formerly worked on both sides of the creek.

At the southeast end of the quarry where the red banded and calico stone occur, the following section was measured:

	Feet.
Shale and soil cover	5
Flaggy sandstone	8
Red banded sandstone ledge	5
Red banded sandstone ledge	2
Red banded sandstone ledge	4
Buff to reddish sandstone	6

The floor of the quarry here is 12 to 15 feet above the creek. The main joint planes run N 45° E and N 45° W, the latter set forming the face of the quarry. A few planes run N 80° E and N 10° E.

At the center of the quarry the following ledges were measured:

	Feet.
Soil and shale cover	5
Flaggy sandstone	10
Buff shales	2
Blue sandstone	6
Blue to gray sandstone	10
Sandstone ledge	2
Sandstone ledge	1
Sandstone ledge	2
Sandstone ledge	1
Sandstone ledge	2
Sandstone ledge	1
Sandstone ledge	5
Sandstone, pink or red	1
Sandstone, pink and banded	2
Sandstone, buff to pink	6

This section shows nearly 40 feet thickness for the quarry face.

Savage Quarry at Charleston.

Mr. P. M. Savage operates a quarry at north end of Capitol street near the Coal and Coke railroad and the city of Charleston. This quarry is one of the oldest quarries near this city, and the stone is used for buildings and crushed for concrete. 20 to 30 men are employed, and 150 to 200 tons of stone are crushed daily in an Austin No. 5 crusher. The stone is said to weigh about 2,700 pounds to the cubic yard.

This sandstone comes at the horizon of the other Charleston quarries described above. The rock is gray or bluish gray in color with foliation planes through it, giving a banded ap-

pearance. The bands are frequently cross bedded, and the stone splits readily along these planes. In the old exposed portions of the quarry, the stone has weathered to a buff color, and at the north end it is shaly and badly broken on outcrop.

Through the rock occur nodules and streaks of coal, which are especially abundant about 20 feet from the top of the quarry down to near the base. The cracks and joint planes are coated with a brown discoloration which sometimes extends a few inches into the stone from the fissure lines, and is due to iron in percolating surface waters. Some of the blocks tend to break with a shelly fracture giving curved surfaces to the stone. In some parts of the quarry small, round, hard, pebbles of quartz occur, also brown chert or flint fragments.

Quarry. The face of the quarry runs north and south, 170 feet long with the old workings extending 80 feet further to the south (see plate XXIII). It has been worked back to the east 75 to 80 feet. A section of the quarry shows the following ledges:

	Feet.	Inches.
Shales and soil cover	10	
Shaly sandstone	30	
Sandstone ledge	4	
Sandstone ledge	3	
Sandstone ledge	6	
Sandstone ledge	8	
Sandstone ledge	10	
Black shale	0	2 to4
Sandstone ledge	30	
Sandstone ledge (not worked at present time)	16	

The joint planes run N. 20° W., N. 50° E.

LOWER FREEPORT SANDSTONE.

Below the Lower Freeport Coal there is a sandstone horizon named by Lesley in Pennsylvania, the Lower Freeport Sandstone. It is described as follows by Dr. I. C. White in Volume II (p. 473): "The rock is usually quite hard, micaceous, and often pebbly, but does not split evenly and

hence is seldom quarried for building purposes. It always makes a steep slope in the topography of the Allegheny series, and frequently crops in bold cliffs along the hills.

"When it first enters West Virginia from Pennsylvania and Ohio in the northern Pan Handle of Hancock county, it is quite massive and often 75 to 100 feet in thickness. It crops in a bold bluff at New Cumberland, and is the great cliff rock at the "Falls" on Harden run, one mile east from that town, where it is nearly 100 feet thick in one massive ledge.

"It is also the same stratum that crops in high cliffs at the mouth of King's Creek, three miles below New Cumberland, and which is quarried on a large scale by S. Casparis, one-half mile up that stream, where it shows an unbroken face of sandstone ninety-five feet high. It yields stone of many grades, and much of it cannot be used, except for the coarser grades of rough foundation structures. This is the only locality in the state, known to the writer, where this rock has been successfully quarried.

"Ten miles below the mouth of King's Creek this stratum sinks below water level of the Ohio, and it is seen no more along that stratum until we pass beyond the southwestern boundary of the state, where it finally comes up again and and makes bold bluffs near Ironton, Ohio.

"When this horizon comes up to the surface on the western slope of the Chestnut Ridge anticlinal, in eastern Monongalia and Marion counties, it is not so thick and massive as in Hancock, and it frequently holds a coal bed (Upper Kittanning) near its center, but east from Chestnut Ridge, where it crops along Raccoon creek, above Austen, it thickens to seventy-five feet or more in one unbroken mass, and the same thickness was found in the Newburg shaft, a few miles west.

"There is also much massive sandstone at this horizon along Valley river, between Powell and Bush, over the crown of the Chestnut Ridge arch, at the Marion-Taylor line."

Casparis Quarry at Kings Creek, Hancock County.

The Casparis quarry is located one-half mile above the mouth of Kings Creek, four miles south of New Cumberland and is connected by a switch with the Pennsylvania railroad. It was opened 18 years ago and is owned by the Kings Creek Quarry Co., a branch of the Casparis Stone Co., of Columbus, Ohio. It is one of the largest quarries in the state, and four to five car loads of stone are shipped daily during the working season.

The Lower Freeport coal, 22 inches thick, outcrops at the top of the quarry, and the Middle Kittanning coal, 34 inches, is at the bottom of the quarry with a thick fire clay seam below it. The interval between the two coals is 84 feet, filled by this sandstone which is the Lower Freeport Sandstone. The stone is blue in color but weathers to a brown or buff. It is a hard, rather fine grained rock, durable under exposure. This sandstone is shipped for bridge piers, culverts, building stone, and curbing. The quarry is operated under the direct supervision of Mr. Jos. Commeaux.

Quarry. The face of the quarry runs northeast-southwest, with an exposed length of nearly 900 feet, though the face of the present working quarry is 200 feet, and worked back about 100 feet. The stone is quarried in large blocks and splits readily. A section of the working quarry shows,

	Feet.	Inches.
Shales and shaly sandstone cover...........	20	
Coal, Lower Freeport........................	1	10
Clay and shale..............................	4	
Buff and blue sandstone ledge...............	10	
Buff and blue sandstone ledge...............	10	
Buff and blue sandstone ledge...............	6	
Buff sandstone	15	
Blue sandstone	15	
Coal, Middle Kittanning.....................	2	10
Clay, shown by boring.......................	10+	

The stone dips to the southwest. The northeast-southwest joint planes determine the direction of the face of the quarry, another set runs almost north and south and are 15 to 20 feet apart.

Chemical Composition. An average lot of this sandstone was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	95.56
Iron and alumina	2.65
Lime oxide	Trace
Magnesium oxide	0.18
Moisture and loss	1.45

The physical tests on this sandstone are given in Chapter XXVI.

Microscopical Structure. Mr. S. L. Powell makes the following report on a thin section of this sandstone (see 3 plate XX): "The section shows the rock to be essentially a quartz sandstone, with feldspar both orthoclase and plagioclase, mica pyrites more or less altered, and kaolin.

"The feldspars are in some cases fresh and apparently unaltered, in others kaolinized, and some completely broken down giving rise to areas of saussurite. There is considerable amount of a dark, opaque, cherty substance containing iron oxide. Flakes of muscovite are common in the section and hand specimen.

"The cement is chiefly silica which has extended and united the quartz grains, often completely filling the interstices. The section shows the rock to be very porous but this is emphasized by the loss of interstitial matter, such as kaolin and the cherty opaque substance, during the process of grinding the section. The rock is somewhat similar in texture and structure to the Gaston quarry stone already described but there is less development of secondary minerals. The grains of quartz vary greatly in shape, from round to irregular and angular forms. The average size of the grains is about 0.35 millimeter."

Toronto Pulp and Grindstone Quarry at New Cumberland Hancock County.

Mr. S. B. Stewart opened a few years ago a quarry near the plant of the West Virginia Fire Clay Mfg. Co., one mile

below New Cumberland at the side of the Pennsylvania railroad. The quarry is operated under the name of the Toronto Pulp and Grindstone Co., of Toronto, Ohio.

This sandstone comes just above the lower Kittanning coal and clay, and has cut out the Middle Kittanning coal. The interval above this coal and clay is often filled in other areas with a mass of shales, but in this section shows a massive sandstone. The sandstone below the coal is known as the Lower Kittanning sandstone, while the one above is the Lower Freeport Sandstone. It has been quarried in past years above Globe north of New Cumberland, and also south of Chester.

The stone on fresh fracture is blue in color, weathering brown to buff. It is fairly coarse sand with small flakes of mica scattered through. The rock is apparently improving in quality as followed into the hill. It is shipped for building stone, foundations and trimmings. It has been cut into grindstones and for glass cutting wheels and for pulp mills. The pulp mill stone is cut 54 inches in diameter with a 27 inch face, while the glass grinding stone can be obtained in this quarry 72 inches in diameter with a 12 inch face.

Quarry. The quarry is located above the level of the railroad track, so that the stone can be loaded by gravity on cars, and the waste rock is carried by an overhead track to the Ohio river bank. The total height of the rock face is 70 feet, but the upper 10 to 15 feet is shaly and not used. Twelve feet of the lower edge, blue in color, is said to be especially adapted to the manufacture of the glass grinding and pulp wheels.

CLARION SANDSTONE.

This sandstone is not quarried at any locality in the state and the following description of the rock is given by Dr. I. C. White in Volume II (p. 494):

"In Pennsylvania and in the northern Pan Handle of West Virginia, a massive sandstone, much resembling the top of the Pottsville, occasionally makes its appearance in the interval between the Lower Kittanning coal and the next un-

derlying coal, to which the name Clarion sandstone has been given by the Pennsylvania geologists. It is seldom present except when the Ferriferous limestone is absent, or but poorly developed.

"Other localities in West Virginia, outside of Hancock county, at which this sandstone can be identified with a fair degree of certainty, are at Valley Falls, near the Marion-Taylor line, where it forms a massive ledge over the Clarion coal, just above the "Falls" in the Valley river; also along Cheat river in Preston and Monongalia, and in the North Potomac basin of Tucker, Grant and Mineral counties, where a massive sandstone is frequently present at this horizon."

POTTSVILLE SERIES.

ROARING CREEK SANDSTONE. (HOMEWOOD SANDSTONE.)

The Homewood or Roaring Creek sandstone, according to Dr. I. C. White[1] is "a great massive, coarse, current bedded and often pebbly, grayish white sandstone that is finely exposed along the lower portion of Roaring Creek, a stream emptying into the Tygart Valley river, just west from Big Laurel Mountain in Randolph county, West Virginia, and hence the stratum in question has been designated from that locality, the Roaring Creek Sandstone. * * * *

"As exposed along the Tygart river this great sandstone conglomerate has every physical characteristic of the genuine Pottsville sediments, and, moreover, it sometimes unites with other underlying divisions of the Pottsville and forms a solid sandstone and conglomerate mass 200 or more feet in thickness. * * * * It appears to correlate in every way with the Homewood sandstone, the uppermost member of the Pottsville series of western Pennsylvania and Mr. David White states that the fossil flora of the roof shales of the underlying Stockton coal confirms this reference.

"The Roaring Creek sandstone goes under the Buckhan-

1. W. Va. Geol. Survey, Vol. II-A p. 488.

non river below Lemley Junction, and does not come out from beneath the same until we pass Hampton, six miles above the town of Buckhannon, beyond which to Sago its immense boulders litter up the stream. It forms great lines of cliffs on either side of the Buckhannon river above Sago gradually getting higher above the same until it escapes into the air from the summits of the mountains near Pickens. It is the stratum which furnishes the glass sand at Craddock, Upshur county, just as it does at Sturgisson on Deckers Creek, Monongalia county, and at numerous points in western Pennsylvania."

Haskins Quarry at Junior, Barbour County.

At Junior 14 miles west of Elkins on the Western Maryland railroad, Mr. Ryland G. Haskins opened a quarry in 1896 at the south edge of town, which was operated by him until 1906 when it was abandoned. Mr. L. N. Viquesny now operates a quarry in this same sandstone across the river.

The top of the Haskins quarry is 60 feet below the Roaring Creek (Lower Kittanning) coal mine opened a mile east. The stone would come at the horizon of the Roaring Creek or Homewood sandstone, the uppermost member of the Pottsville series. The stone varies in color from yellowish white to red, and variegated colors. It was used as building stone and crushed in a Gates crusher for ballast.

Quarry. The face of the quarry runs north and south, 400 to 500 feet long and worked back 40 feet to the county road line. The rock dips north, and followed in that direction, the layers become shaly on outcrop. The quarry is between the Western Maryland railroad and the county road, and has been mostly worked out to the road. In places the stone has a vertical face of nearly 30 feet. A section of the quarry shows,

	Feet.
Soil cover	2
Shaly sandstone	6
Sandstone	5
Yellow clay	1
Sandstone	10
Shaly sandstone (1 to 4 inch layers)	4

The floor of the quarry is still sandstone. The joint planes run N. 40° E, and N 20° E.

Chemical Composition. An average lot of this stone was analyzed in the Survey laboratory with the following result:

	Per cent.
Silica	97.29
Alumina	1.29
Iron	0.39
Lime oxide	0.04
Magnesium oxide	0.07
Alkalies	0.29
Loss on ignition	0.63

This analysis shows a very pure sandstone, with low alumina, so that the cement is probably silica making a very durable stone. The microscopical structure is probably very similar to that of the Riverside quarry described in the following section.

Riverside Stone Company Quarry Near Laurel, Barbour County.

Workman Brothers have operated for the past few years the quarry originally opened by L. N. Viquesny and A. J. Workman in September, 1895. This quarry is located at the side of the Western Maryland railroad, two miles east of Junior, a mile west of Laurel station, or twelve miles west of Elkins.

The Roaring Creek (Lower Kittanning) coal comes about 30 or 40 feet above the top of this quarry, so the sandstone is the Roaring Creek (Homewood). The stone shows a variety of colors, blue, buff, yellow, pink, reddish; and some of the ledges have an irregular red banding in the yellow stone, and named by the quarrymen, the calico stone. The texture varies from fine to coarse grain, and at the base of the hill is a coarse white pebble conglomerate. Some of the ledges are foliated or banded, the planes lined with white mica flakes. Yellow or red iron dots give a spotted appearance to some of the stone.

The lower ledge of the quarry has a bluish gray color,

strongly banded and breaks with smooth surfaces glistening with both white and black mica. It is composed of very small round quartz grains giving a close grained texture.

The stone has been extensively used in Elkins and also shipped to other places. It is especially popular for fronts of buildings and trimming stone. The variety of colors permits its use with any color brick, and affords variety of color in adjoining buildings. Eight to ten men are employed and a car load of stone is shipped daily during the working season. The rock is also crushed for building sand, and the mill has a capacity of 45 tons a day. About 250 tons are crushed daily for use in concrete.

Quarry. The floor of the quarry is 100 feet above the railroad track and is connected with the railroad by a 315 foot incline. The working quarry is 500 feet long with the face north and south, and it is worked to the east, 160 feet wide. A section of the quarry shows,

	Feet.
Shales	2
Pink or reddish sandstone	13
Buff or yellow calico stone	18
Brown or buff sandstone	16
Blue to black shale	1
Buff sandstone	4
Blue, foliated sandstone	5

Below the floor of the quarry is a blue and buff, but mostly blue foliated sandstone that extends for 30 feet down the hill, and the upper portion is now quarried. In the upper ledges of the quarry fossil stems of plants occur here and there, and some black carbonaceous spots. At the railroad level or 100 feet below the bottom of the quarry is a ledge of coarse conglomerate rock reaching 40 feet up the hill.

Microsocopical Structure. Mr. S. L. Powell makes the following report on a thin section of this sandstone:

"The rock is essentially a sandstone composed originally of more or less rounded grains of quartz sand, with a few scattered grains of feldspar and some kaolin. The cement is essentially silica. Kaolin and a few kaolinized feldspars occupy a certain portion of the interstitial space, but silica

Plate XXII.—Coal and Coke Railroad Quarry in Mahoning—Freeport Sandstone on Elk River above Charleston, Kanawha County.

largely predominates. The quartz grains have grown by addition of silica until they have united into a comapct mass. Sufficient iron stained kaolin is present to give the rock a tinge of color. The quartz grains are angular and rough due to the enlargement by silica, and they average about 0.5 millimeter in diameter."

Brydon Ganister Quarry at Bloomington, Mineral County.

Bloomington is a small station on the main line of the Baltimore and Ohio railroad, two miles west of Piedmont. At this place is located the only ganister rock quarry in the state, though there are many other places where such rock could be obtained.

Ganister rock is a siliceous sandstone which is refractory and is used for lining Bessemer converters in manufacture of steel. The Bloomington rock has proved very satisfactory for this purpose and is shipped mostly to Pittsburg. This quarry was opened in 1900 and is operated by J. C. Brydon and Company of Grafton, West Virginia. The stone is quarried entirely for ganister and fire stone. Eight to twelve men are employed and 25 to 30 cars are shipped a month in the working season.

The rock is gray to grayish white in color, with some pink and reddish layers. It varies from fine to coarse grain in texture and is very hard. Some of the stone is banded and then splits along these planes. The bedding is curved and irregular, and the quarry shows a badly broken face. The stone dips to the west.

Quarry. The quarry is 80 feet long north and south, and an old abandoned quarry lies to the north. It is 30 feet wide east and west and to the east has been worked out 30 feet more through a mass of badly broken stone and river boulders eight feet high.

A section of the quarry shows,

	Feet.
Soil cover and river boulders.............	4
Sandstone, seamed and broken............	25
Fire clay, and traces coal blossom........	4

The joint planes run N 50° W and N 30° E but are irregular. The rock is partly broken by sledges into blocks 8 to 10 inches thick and then is further broken by dropping a heavy iron weight raised by the derrick.

Chemical Composition. An average lot of this stone was analyzed in the Survey laboratory and showed the following percentages of components:

	Per cent.
Silica and insoluble	96.50
Iron and alumina	2.44
Lime oxide	0.39
Magnesium oxide	0.07
Moisture and loss	0.49
Alkalies	0.26

Gowing Quarry Near Dellslow, Monongalia County.

On the D. H. Gowing land one mile east of Dellslow station on the Morgantown and Kingwood railroad, about seven miles east of Morgantown, a quarry was formerly operated and the stone used in the B. & O. railroad tunnel on the Cumberland cut-off line. This quarry has not been in operation for the past five years.

The stone is in the uppermost portion of the Pottsville or Homewood Sandstone, which is dipping steeply to the west and passes below the track level a short distance west of the quarry. The rock varies in color through the quarry and even in the same ledge. The lower and the top ledges are mostly gray in color, with brown to reddish layers near the center of the face. It varies from fine to coarse grain in texture, with conglomerate layers. Mr. Tony Pietro, contractor, has quarried this stone about one half mile below this quarry, for use as curbing in Morgantown. The stone at this locality has a reddish white color due to spots of iron oxide.

Quarry. The floor of the Gowing quarry is 72 feet above the railroad. The face of stone exposed, is 100 feet long and worked back 30 feet. A second quarry was opened a short distance to the east, and the stone could be quarried, with a

length of one-half mile. A section of the quarry shows the following ledges:

	Feet.	Inches.
Cover of irregular, flaggy sandstone	2	
Reddish brown, coarse grained sandstone	3	
Shaly layer with small clay masses	0	4
Hard, banded sandstone with streaks of pebbles	5	
Bluish gray sandstone with yellow bands	4	6
Reddish sandstone, banded or foliated	8	
Close grained, white sandstone	1	
White conglomerate, small pebbles	10	
Gray to white sandstone	3	
Yellowish gray to white sandstone with streaks of pebbles	10	
Reddish sandstone	2	
Yellowish, mottled sandstone	8	

The joint planes run N 40° W, N 70° E, N 10° W, the last making the face of the quarry, also N 5° E. The physical tests on this stone are given in chapter XXVI.

Decker's Creek Sand Company Quarry at Sturgisson, Monongalia County.

The Decker's Creek Sand Company of Morgantown operate a quarry at Sturgisson, nine miles east of Morgantown on the Morgantown and Kingwood railroad. The stone is crushed for building and glass sand. Its use as glass sand and also the other glass sand quarries in the Homewood sandstone are described in Chapter XVII of this report. This stone varies in color from white and bluish gray to yellow. It breaks in blocks in which the sand grains are loosely cemented, so that it is readily crushed.

Quarry. The top of the quarry incline is 550 feet above the floor of the mill as measured by barometer, but it is claimed at the plant that a transit level showed 620 feet. The quarry is worked 60 feet wide and the further end is 360 feet back of the top of the incline. The face runs N 40° W, and worked to the southwest.

The face is 30 feet high in the present quarry whose floor is 18 feet higher than the rock floor at the incline. The north-

east face of the quarry is badly broken and more irregular. At the base is a shaly sandstone with some good ledges below it. The stone dips N 20° W, and on the other side of the quarry dips at about the same angle in opposite direction, while at the base of the quarry are three ledges dipping N 40° E. The joint planes run N. 40° W, N 50° E, and a few N 50° W. These planes are usually stained with iron, giving the surface a red or yellowish color, and some of the planes are filled with vertical slabs of broken rock.

CONNOQUENESSING SANDSTONES.

This important group of two sandstones in Pennsylvania and Ohio is not well developed in West Virginia, and is not quarried at any place in the state. They were named in Pennsylvania by Dr. I. C. White[2] who described them as follows:

"Each of these sandstone members is from 40 to 50 feet thick, though occasionally the shale and coal separating them thins out and they coalesce in one mass 150 to 200 feet thick, or even more. They are generally quite hard, the quartz grains being finer and more compactly arranged than in the Homewood sandstone above. The color is more frequently yellowish white than any other, though sometimes it is gray."

The Sharon Conglomerate at the base of the Pottsville Series is an important stratum in Ohio and western Pennsylvania but is not quarried at any place in West Virginia.

COALBURG SANDSTONE.

In the southern part of West Virginia in the Kanawha Series of Dr. I. C. White, there occur a number of sandstone strata, only one of which is quarried on any large scale. This series is correlated by Dr. White with the Upper Pottsville, and the various sandstones of the southern section are described by Dr. I. C. White, in his recent coal report, Vol. II-A of the West Virginia Geological Survey, to which the reader is referred for more detailed information.

2. U. S. Geol. Survey, Bull. 65, p. 201.

The Coalburg sandstone is found a short distance above the Coalburg coal and is described as follows by Dr. I. C. White (Vol. II-A, p. 468): "It is generally a coarse bluish gray rock and often weathers into 'Chimney towers' and 'Table rocks' especially when exposed on summits.

"It has been extensively quarried by the Kanawha Stone Company and other parties, about two miles above Charleston on the north bank of the Great Kanawha river, where it is 40 to 50 feet thick and holds some large nuggets of limy material at 25 feet below its top. This is one of the great cliff horizons in the Kanawha series, and its outcrop is always a prominent feature in the topography along the Great Kanawha and other streams where it exists in good development."

Kanawha Stone Company Quarry at Charleston.

Mr. W. L. Couch in February, 1906, organized the Kanawha Stone Company to operate the old quarry opened 75 years ago on the Ruffner farm, one mile and a half southeast of Charleston on the Kanawha and Michigan (T. & O. C. railroad) at the station of Alum Springs.

Just above the sandstone the Stockton Coal, four feet in thickness, outcrops, and the springs from this coal are heavily charged with alum, and are known as the Alum Springs. Twenty-five feet below the sandstone is the Coalburg coal one foot thick. This heavy sandstone above the Coalburg coal has recently been named by Dr. I. C. White the Coalburg Sandstone. The stone on weathered outcrop is brown, or buff in color, and in freshly quarried stone is blue to gray. It is banded with mica and often along these bands are plant remains and coaly material. All through the stone occur these bituminous masses and fossil plant stems.

Quarry. The floor of the quarry is 67 feet above the M. & K. railroad track, or about 80 feet above the Kanawha river. The face of the quarry runs east and west, 150 feet long, and worked to the north about 40 feet. A section of the main quarry shows,

	Feet.
Soil and some shale	4
Shales in fairly compact ledge	6
Coal, Stockton	4
Flaggy sandstone	4
Very shaly sandstone	3
Sandstone	5
Gray sandstone ledge	5
Gray sandstone ledge	10
Thin black slate or coal streak	..
Coarse gray, foliated sandstone	14
Brown or buff sandstone	2

The sandstone continues down 20 feet or more below the quarry floor to the coal, but only a few feet of the top of this portion has been quarried. The 3 feet of very shaly sandstone below the Stockton coal, pinches out at the west, and the next ledge of five foot sandstone then thickens to 10 feet. The joint planes run N 70° to 80° W, and N 40° to 50° E.

A new quarry in this same sandstone has been opened a short distance to the east and is used mainly for building stone. The stone is light gray in color, but numerous springs flow down over the face, carrying iron which has stained the outcrop a red or brown color to a shallow depth. The stone is foliated and contains, streaks and particles of coaly material. The foliation planes are parallel to the bedding, and at right angles to them is often a series of brown lines due to iron stain from water. These brown lines are more or less curved and irregular, as the water followed the lines of easier access through the stone. The stone splits readily into blocks of desired size.

Quarry. The face of the new quarry runs N 70° W, 125 feet in length, and worked to the north 20 to 25 feet. A section at the middle of the quarry shows,

	Feet.
Soil cover	2
Shaly sandstone	5
Buff shales	2
Gray sandstone ledge	10
Gray sandstone ledge	12 to 14

At the east end of the quarry the two lower ledges are solid and show unbroken face of 22 to 24 feet.

The stone from these quarries has been used at different

times for building stone during the past 75 years. The foundation of the old Ruffner house at the corner of Kanawha and Ruffner streets in Charleston, was built of this stone in 1834. A close examination of this foundation shows that it is in good condition today, and it still shows the chisel marks clearly. The stone is in good demand in the city, and the company has been busy all of the past season.

The stone in the west or old quarry is largely crushed for concrete. One hundred to 150 yards are crushed daily and loaded from storage bins by gravity into the railroad cars. In the working season, 20 to 25 men are employed. One cubic yard of this stone is said to weigh 2,500 pounds.

CHAPTER XXIV.

SANDSTONES OF THE LOWER CARBONIFEROUS, DEVONIAN AND UPPER SILURIAN.

LOWER CARBONIFEROUS.

Mauch Chunk sandstone.
Alderson sandstone.
Pocono sandstone.

DEVONIAN.

Catskill sandstone.
Chemung sandstone.
Rowlesburg sandstone.
Oriskany sandstone.

UPPER SILURIAN.

Clinton sandstone.
Medina sandstone.

MAUCH CHUNK SANDSTONES.

Below the Pottsville Series of the Coal Measures is the Lower Carboniferous or Mississippian formation, with its top marked by a great deposit of red shales including limestone and sandstone strata. An explanation of this red deposit is given as follows by Dr. I. C. White (Vol. II-A, p. 10):

"Succeeding the deep sea deposits of the Greenbrier limestone, and the subsidence which characterized the same, there supervened an epoch of elevation of the Carboniferous sea

bottom until the southeastern margins at least of the Appalachian field had become land. From these old land surfaces, the rivers of the time poured into the Appalachian sea a flood of red mud deposits, some of which were doubtless derived from the erosion of the red beds of the Catskill formation whose upturned edges now make a great zone of red sediments from New York to southwestern West Virginia.

"These red beds alternating as they do with impure limestones, massive sandstones, and conglomerates, reveal the contest being waged for supremacy between subsidence, and deposition, the one carrying down the sea bottom, and the other filling it up."

At two places in this state, the sandstones in the Mauch Chunk formation, have been quarried. Both were abandoned on account of lack of railroad facilities at the time and the resulting high cost of transportation, and at both places at nearly opposite ends of the state, the stone was exceptionally hard and durable.

ALDERSON SANDSTONE.

Alderson Brownstone Quarry near Alderson, Monroe County.

The quarry of the Alderson Brownstone Company of which Mr. James D. Crump of Richmond, Virginia, is president, is located five miles west of Alderson up Griffith Creek, and three miles from the station of Mohler on the Chesapeake and Ohio railroad.

The sandstone comes in the red shales of Mauch Chunk formation and may possibly represent the Princeton Conglomerate of Campbell. The stone is very hard, red to brown in color and weathers to a dark brown. It is very close grained in texture composed of very minute quartz grains cemented by silica, so that it is almost quartzitic in structure. Very small flakes of white mica occur through the rock. It readily splits along the bed, but is difficult to break at right angles to this direction. On the outcrop the stone breaks flaggy. There are numerous traces of mud cracks and ripple marks, showing the stone to be a shallow water formation.

Quarry. The face of the quarry runs N 50° E, 250 to 300 feet long, and it has been worked back 40 to 50 feet. When the quarry was in operation, fourteen years ago, an incline track led down to the valley and four miles down to the railroad. Since that time the Glenary Lumber Company has built a standard guage railroad up Griffith Run about a mile from the quarry and 600 feet lower. A section of the quarry shows,

	Feet.	Inches.
Red shales, finely laminated	18	
Nodular sandstone	0	10
Gray sandstone	12	
Red or brown sandstone	6	
Brown sandstone	16	
Gray sandstone	4	

The stone on weathered surface of the quarry shows a division into thin ledges as follows:

	Feet.	Inches.
LEDGE	3	
"	2	
"	0	10
"	1	
"	2	6
"	2	
"	0	8
"	0	8
"	0	8
"	0	8
"	1	
"	1	
"	1	
"	3	
"	0	8
"	0	10
"	0	10
"	0	8
"	1	
"	4	
Total	26	10

This section of ledges begins six feet from top of quarry and stops six feet from the bottom. The joint planes run N 50° E which determine the face of the quarry, also N 20° to 30° W. The physical tests on this sandstone are given in Chapter XXVI.

Uses. The stone was shipped to Charleston and other cities on the Chesapeake and Ohio railroad for ornamental trimming stone. It has also been used at Richmond, Virginia, for building stone. In color it makes a pleasing contrast with buff and red brick fronts.

Blocks of this stone were cut 10x7x5 inches in large quantity for street paving blocks, and shipped as far west as Columbus, Ohio. The stone is hard enough to give good wearing qualities and had good sale for this use. The work at the quarry stopped on account of the cost of transportation over the crude tram road. At the present time, with the railroad in the valley below, this stone could be worked and it should prove a profitable investment to reopen this quarry.

A similar red sandstone was worked for many years near Hinton, Summers county, on the C. & O. railroad. It has similar qualities to the Alderson stone and comes in the same geological formation. This quarry has been idle for eight or ten years.

Chemical Composition. An average lot of the Alderson quarry stone was analyzed in the Survey laboratory with the following results:

	Per cent.
Silica and insoluble	90.90
Iron and alumina	4.61
Lime oxide	1.34
Magnesium oxide	0.70
Moisture and loss	2.50

The analysis shows a rather high percentage of iron and alumina, probably more iron than alumina which determines the color and probably forms a portion of the cement along with the silica. The lime percentage is higher than most of the sandstones of the state.

Microscopical Structure. Mr. S. L. Powell makes the following report on a thin section of the Alderson sandstone (see 1 plate XX):

"This rock is a very fine, even grained brown stone, formed by the consolidation of a sediment composed of about 50 per cent moderately well rounded quartz grains, a consid-

erable amount of feldspar and mica, a few zircon and tourmaline fragments, and some kaolin.

"The quartz grains, though varying in size and shape, would average about 0.2 millimeter in diameter. In many instances they have undergone enlargement by the addition of silica which has formed a considerable portion of the cement. This is noticeable not only where the grains had a coating of iron previous to such addition of silica, but in numerous instances where they have grown into completely interlocking areas.

"The feldspars are in some cases, fresh and clear showing characteristic twinning, and in others are completely altered to silica, muscovite, and kaolin. There is in addition a considerable development of calcite, chlorite, and oxide of iron which gives color to the rock. The cement is essentially silica and iron oxide, which together with the secondary minerals, calcite, chlorite, and muscovite, completely fill the interspaces making it a firm, compact rock."

Stoer Quarry Near Manheim, Preston County.

On the lands of John F. Stoer of Philadelphia, located two miles below Manheim, or five miles from Rowlesburg, down the Cheat river, a blue and buff sandstone has been quarried at the side of the Morgantown and Kingwood railroad. The stone was used in the construction of the buildings, for the Buckhorn Portland Cement Company plant at Manheim, and was then abandoned.

The sandstone comes in the shales above the Greenbrier limestone and 500 feet below the Pottsville conglomerate. It therefore belongs in the Mauch Chunk formation. The stone is blue and buff, or locally called gray in color. It is a very hard, compact rock, but breaks readily parallel to the bed with smooth planes coated with glistening mica flakes. The blue or gray rock often has a greenish tinge, and is so fine grained that with a lens the quartz grains cannot be distinguished. Some of the courses especially in the blue ledges are flaggy.

Quarry. The floor of the quarry is 18 feet above the M. & K. railroad. The face runs northeast-southwest, and it was

worked to the east. The main joint plane determines the direction of the quarry face and runs N 30° E. A section of the quarry shows,

	Feet.	Inches.
Chocolate brown shales	8	
Buff shaly sandstone	10	
Buff flag sandstone	12	
Blue shale	1	
Blue sandstone, flaggy	1	6
Buff and some blue sandstone	10	

From the bottom of the quarry to the railroad track, the sandstone is quite flaggy on outcrop and blue in color. While most of this stone now exposed is a buff or brownish color, it is very probable that as the stone is followed into the hill, it will become blue in color. The flaggy character of some of the ledges will probably change and the rock become more solid. The stone dips strongly to the north and passes under the river in a short distance.

The main joint planes run N 30° E, and while there are some small cracks at right angles to these planes or nearly so, there are no well defined joint planes visible.

Microscopical Structure. Mr. S. L. Powell makes the following report on a thin section of the buff or brownish sandstone from the Stoer quarry:

"The section shows the rock to be a finely granular sandstone, originally composed of grains of quartz, feldspar, mica, kaolin, and other ferro-magnesian minerals, with a few zircons. Many of the quartz grains were originally well rounded, but now all are more or less angular, due to secondary enlargement by silica which forms part of the cement. The greater portion of the interstitial matter, however, is due to the development of secondary minerals, such as chlorite, muscovite, kaolin, and calcite, which originated from the alteration of the feldspars, mica, and other ferro-magnesian constituents.

A considerable amount of the ferric iron has also developed which gives color to the rock, and forms part of the cement. This intricately intergrown secondary mineral matter is very abundant and forms the matrix or ground mass

for the quartz grains and remaining feldspars. The average diameter of the grains is about 0.25 millimeter."

The greenish blue, or locally called gray, sandstone from this quarry was also examined in thin section by Mr. S. L. Powell who makes the following report:

"This rock is finely granular, the grains varying from minute particles to 0.4 millimeter in diameter. The shape of the grains is very irregular, varying from a few rounded individuals, to jagged, frayed, triangular, and elongated forms. But few interstices between the grains remain unfilled, and the rock is, therefore, very compact and almost non porous.

"Quartz is the most abundant mineral present, next in amount are a few feldspars, and occasionally an altered biotite. Flakes of kaolin are abundant. The only change in the quartz is that due to enlargement by secondary silica, extending the grains until in many instances they completely interlock in the formation of larger quartz areas. In addition there are other independent areas of secondary silica filling the interspaces.

"A few plagioclase feldspars remain practically unaltered and show characteristic twinning. The greater portion of the feldspar is either much altered or completely broken down into aggregates of secondary minerals, muscovite, chlorite, calcite, and quartz, which completely fill the interstices between the grains. In some cases instead of a mosaic of these minerals, there is a considerable development of sericite or chlorite, as if from a source other than feldspar, probably some original ferro-magnesian constituent. These secondary minerals together with the silica constitute the cement which forms a very resistant bonding material. The color of the rock is due to the large development of secondary minerals, chlorite, especially which gives the greenish tinge to the rock."

The basal member of the Carboniferous Group of rocks is the Pocono sandstone which is not a quarry rock at any place in the state. Its economic value is in its gas and oil accumulation in the so-called Keener and Big Injun sands.

Plate XXIII.—Savage Quarry in Mahoning—Freeport Sandstone at Charleston, Kanawha County.

DEVONIAN SANDSTONES.

The Catskill sandstone is not quarried in this state. A very durable brown sandstone outcrops high on the hills opposite Rowlesburg in Preston county, and apparently corresponds in position to the Catskill. It has been opened as a quarry prospect by Mr. John F. Stoer, and shows a good ledge of rather fine grained brown sandstone which would doubtless prove to be a very popular trimming stone.

ROWLESBURG SANDSTONE.

Preston Blue Stone Company Quarry at Rowlesburg.

Rowlesburg in Preston County is 26 miles east of Grafton on the main line of the Baltimore and Ohio railroad. It is also reached by the Morgantown and Kingwood railroad. At this place on the east bank of Cheat river and near the B. & O. railroad bridge, Mr. H. W. Rightmire operates a sandstone quarry under the name of the Preston Blue Stone Company.

The floor of the quarry is below the level of the railroad about 15 feet above Cheat river. The hill back of the quarry rises 800 to 900 feet higher, but does not reach the Greenbrier limestone. The sandstone comes in the Upper Devonian probably at the Chemung-Catskill horizon. The rock varies in color from a gray or slate color to a green or greenish blue. It is close grained and very hard, with white mica flakes and very small quartz grains. It does not show a distinct banding except in a few places, but splits readily parallel to the bed planes, so that while very hard, it is readily worked. The stone can be broken into flags, and the upper courses are so used. Some of the bedding planes are polished smooth almost slicken-sided. The overlying shales are ripple marked.

The color is uniform and durable, and this quarry furnishes one of the most attractive trimming stones in the state, and it is shipped to many eastern cities. It was used in the trimmings of the Johns Hopkins University at Baltimore and in some of the bank buildings in that city. In one

of these bank buildings near the center of the Baltimore fire district the stone passed through that great conflagration with but little injury. It is now shipped in car load lots to Philadelphia and New York. The quarry was first opened nearly 60 years ago.

Quarry. The face of the quarry runs north and south, 350 feet long, and it is worked to the east. The stone is loosened from the wall by light shots and then broken into blocks by use of plugs and feathers to avoid any injury to the strength of the stone. The stone dips to the north about 1 foot in 25 in places. A section at the north end of the quarry not worked at the present time shows,

	Feet.	Inches.
Soil cover	3	
Shaly sandstone	4	
Shales	2	
Sandstone	2	6
Blue shales with sandy layers	10 to 12	
Blue to black shale	1	6
Greenish blue sandstone ledge	3	
Greenish blue sandstone ledge	8	

At the south end of the quarry which is now being worked, the following ledges are exposed:

	Feet.	Inches.
Coarse sandy shales	8	
Blue laminated shales	12	
Buff sandstone	4	
Blue shales	2	
Bluish gray sandstone, irregular	3	6
Drab to gray sandstone	1	6
Shale	0	½
Greenish blue to gray sandstone	0	6
Shale	0	1
Greenish blue to gray sandstone	0	6
Shale	0	1
Shaly sandstone	0	6
Shales, blue and buff	3	
Buff or brown sandstone	4	
Greenish blue, foliated sandstone	5	
Greenish blue and buff sandstone	5	

The lower 14 feet represent the working part of the quarry and especially the lower 10 feet. The bottom course of two feet is often left in the quarry on account of its darker

color. The joint planes run N 10° E., and due east and west. The physical tests on this sandstone are given in Chapter XXVI.

Microscopical Structure. A thin section of the Rowlesburg sandstone was examined by Mr. S. L. Powell, who makes the following report: "This is a very fine grained, homogeneous, compact sandstone, composed of angular quartz grains, fresh feldspars both orthoclase and plagioclase showing the characteristic twinning, also flakes of mica both muscovite and biotite, iron oxide, and kaolin.

"The cement is abundant and pores few in number. In character the cement is a mixture of minerals resulting from the decomposition of feldspar, mica, and other original mineral constituents such as, chlorite, muscovite, calcite, epidote, silica, and iron oxide. These minerals are completely intergrown firmly uniting the whole into a hard compact rock. The dark green or bluish gray color of the rock is due to the abundance of chlorite and oxide of iron blending with the lighter colored minerals."

The Oriskany Sandstone is not used as a building stone in the state; but it is an important glass sand horizon at Berkeley Springs, and this industry is described in Chapter XVII of this report.

UPPER SILURIAN SANDSTONES.

The Upper Silurian sandstones are not used for building stone in this state at the present time. Their outcrop is found mostly in the mountain area at a distance from railroads. At the top of the Clinton formation there is a gray sandstone, very hard, with an average thickness of 15 feet. This outcrop was seen near Franklin in Pendleton county.

The Medina formation is subdivided into three groups of beds as follows:

The Medina White Sandstone.

Red Medina Sandstone and shales.

Gray Medina Sandstone.

The White Medina sandstone makes the top of North

Mountain, and crops at many points along the eastern boundary of the state. It is one of the great mountain sandstones of the Appalachian belt. It has been quarried for glass sand in Morgan county, and makes excellent railroad ballast.

The Red and Gray Medina beds have not been used for any purpose in West Virginia.

CHAPTER XXV.

THE EXAMINATION AND TESTING OF BUILDING STONE.

In a preceding chapter the properties of building stone have been discussed; and from this discussion, it is evident that stone for building purposes must possess certain essential properties. Stone is variable in its composition, characters, and therefore value. These variations may be noted in different horizons, different quarries, and even in the same quarry. Some stone is not adapted to any permanent use and for enduring structures is worthless, and yet such stone sometimes finds its way into buildings there to be a source of trouble and expense.

It is a most important matter to determine the qualities of stone for building purposes. The present chapter treats of this subject of the proper examination and testing of stone to determine especially its strength and durability. The methods of examination and testing may be grouped under the following heads:

Quarry Examination.
Building Observations.
Laboratory Tests.
Microscopical Examination.
Chemical Analysis.
Physical Tests.

QUARRY EXAMINATION.

A study of the quarry will determine the availability of the stone; its amount of cover, difficulties or advantages of transportation, which must be considered in connection with

the market demand regulating the selling price. Unless there is little competition and a large demand for the stone, a heavy cover will be too expensive to work even a very good quality of stone. The removal of a heavy and resistant cover will prove one of the largest expenses in the quarry development. There is one place in this state where a very successful quarry has practically discontinued work on this account alone. The hauling of stone by wagon to the railroad or city is a proposition of doubtful success. Ordinary size foundation stones will weight 160 to 250 pounds each and 20 such blocks would be a good load over good roads, but the road from a stone quarry will soon be far from good thus limiting capacity of output.

A study of the structure of the quarry including stratification and joint planes will determine the ease and therefore to some extent cost of quarrying, also the size and shape of the blocks. In one blue sandstone quarry of the state it is possible to quarry blocks of a size only limited by the capacity of equipment for hauling the stone. Another quarry in a similar stone not over four miles distant has the stratification planes well developed and only 4 to 6 inches apart causing the stone to break into flags. In all other respects this second quarry would furnish a most desirable stone for ornamental stone fronts of buildings or for sills and caps. It has a pleasing durable blue or gray color, has close texture and high strength.

The effect of weathering agents on the stone can be observed in exposed parts of the quarry. Frost, freezing and thawing may open up the stratification planes showing these to be lines of dangerous weakness in the rock. The stone may posibly crumble under this action by the breaking apart of the rock particles as they expand under freezing of the water in the pores. These observations may show that certain ledges in the quarry are more resistant than others.

The permanency of the color of the stone can be observed in the quarry to good advantage. The long exposed outcropping ledges will usually be quite different from the interior. While the time element involved is uncertain in

this observation, stone may perhaps be found at nearly the same horizon in railroad cuts where the length of the time exposure can be determined and the change in color noted. Nearly all sandstones and most limestones change color on exposure to the air, but the change may be merely to a darker shade and fairly uniform. Such a change is scarcely objectionable. Bluish gray or greenish shades give bright effect to the stone but they are not as a rule permanent, changing to a darker shade or to a buff. This change can be seen in the quarry exposure.

In the quarry one can judge the hardness of the rock, its texture, and an approximate idea of the porosity. These properties will influence the cost of working the stone and also its durability. Differences in hardness in the ledge will appear in the weathered rock, the harder portions projecting as the softer are worn away. Different ledges in the quarry may show variations in hardness and other properties so that certain ones will be adapted to particular line of work while others will be inferior in quality. If these ledges are quarried and sold without any regard to these differences, bad results often follow.

Due allowance must always be made in judging the quality and value of a stone from long exposed outcrops which will exaggerate the defects of the rock. All stone in the ground weathers, forming disintegrated rock and soil. The hard durable granites break down into soil. The rock in the ground is subject to the action of organic acids, to frequent saturation with water, freezing and thawing in this condition, while in a building these agencies would be far less powerful. Stone may thus appear worthless on outcrop which if followed into the hill may be one of the strongest and most durable building stones.

The study of the weathered and unweathered stone in the quarry along the lines suggested above will be most valuable in determining its real value, but care must be exercised in properly estimating the defects and good qualities of the stone.

BUILDING OBSERVATIONS.

The durability of a stone can perhaps be best determined by observations on old structures that have stood the test of time and the atmospheric elements. Unless the stone is exceptionally poor a few years' exposure will have little effect, but a period of 20 years and more will test the stone and determine its value as a building material.

Here again as in quarry outcrop exposures some discriminating judgment is required to form a correct opinion. The apparent defects in some stone buildings as iron stains, efflorescence or white wash, broken sills and lintels may be due to faults in construction. A poor foundation by unequal settling may throw an uncalled for strain on a cap or sill stone, breaking it. Poor mortar may cause staining of the stone, or thick mortar joints becoming broken out may cause strains unequally distributed. Stone from poor ledges may be mingled with the good stone and its poor weather resistance injure the reputation of the whole building and the quarry. Iron brackets, leaking gutters, etc., may result in streaked stone below along the path of drip. Careless handling and dressing of the stone may leave incipient cracks later made prominent by atmospheric forces. All of these modifying influences should be kept in mind in the examination of stone structures.

In one of the cities of this state there is a building stone quarried on considerable scale, bright in color, apparently solid and durable when quarried; yet in buildings less than 30 years old, this stone has on the surface the structure of a loose sand crumbling in the fingers, the wall is pitted and rough. It has failed in the test of time. With this evidence of poor quality, the stone today has a large sale and is regarded by many as a valuable stone. Few specifications are drawn which would forbid its use.

On the other hand in the walls of the old Ruffner house on Kanawha street, Charleston, which was built nearly 100 years ago, the stone is compact and solid apparently as strong or stronger than the freshly quarried stone. In

Clarksburg the Presbyterian Church, and the artistic wall around the Jackson home, after 15 years, have the appearance of recent or new structures.

In the construction of foundations for frame, brick, and even stone buildings, the primary object in the selection of stone is too often cheapness. Any kind of stone that is conveniently at hand and especially a stone that works easy is selected. It will hold in good condition for the present and the future can take care of itself. This policy is far from a safe one for buildings that are expected to stand for long periods of time.

A popular style of building a stone house at low cost is the stone veneer. In this form there is the temptation to use slabs of stone set on edge. Some stone will prove durable set in this way, many varieties of stone will not, and the safe rule is to assume stone set on edge will not prove satisfactory, unless actual tests are available to prove its durability. The foundation of the tower on the main building of the Ohio State University at Columbus, Ohio, was made of large blocks of stone set on edge, finally to save the tower the foundation had to be replaced, though for years it appeared to stand with little or no trace of danger. In an old cemetery near Clarksburg, sandstone split in two inch slabs and set on end as tombstones after 100 years' exposure, shows no effect of cracking or spalling along the bed planes. The stone is apparently as enduring as though laid on its bed. There is absence of any pressure on the stone, which would be present in a building.

The durability of a stone under the very severe test of fire can be judged by examination of the buildings after a conflagration. In the Baltimore fire, granite, limestone and sandstone buildings showed the serious injury by spalling and cracking under the great heat. It is an exceptional stone that would pass through such a test uninjured, but some varieties of stone show less injury than others. The Rowlesburg, West Virginia, sandstone in one of the buildings in the heart of that fire district escaped with but slight injury showing its admirable fire resistant quality.

After some of the small fires in some of our home cities, it is instructive to notice the resistance of the stone to the heat action. Useful information can thus be gathered as to the fire effects on the native stone that might be valuable in future construction.

The permanency of color in buildings exposed to the air with its gases, smoke, etc., can be observed in the different buildings. It is important to know not only the permanency of the color, but the character of its changes whether uniform or not. These points can be best observed in actual use. It is interesting to see in some cities stone in buildings of equal age and under like conditions, one bright and the other dark and dingy. Such differences may be due to actual chemical changes in the stone color or due to one stone retaining the soot and dirt more than another.

The disagreeable effects of iron stains, efflorescence due to soluble salts in the stone are seen in stone buildings. As has been stated this may be due in some cases to the mortar or cement used, and greater care should be taken in selection of cement or lime. One wall of stone in a city of this state was noticed stained with white streaks marring an otherwise beautiful structure and this was generally believed to be a fault of that particular stone. Careful examination showed it to come from the cement used in laying the wall.

It must also be kept in mind that a stone durable in one locality may not be durable in another with different climate. The loose shell rock of Florida serves a useful purpose in buildings in that region, and would be worthless in the changeable northern climate. The stone monoliths standing for ages in Egypt when brought to New York commence to crumble in a few years and must be coated with a preparation to preserve the structure.

The durability of a stone for sidewalks, steps, curbing, etc., can be observed by examination of stone used for these purposes. Some very poor stone has been used in curbs and sidewalks, and shows disintegration in a very short time. For use as curbing the stone is usually set on edge, the blocks being split out in proper size. The stone must break readily

into these blocks and must have sufficient strength to resist weathering action when placed on edge. There are a number of sandstones in this state adapted to use as curbing, and some of the stone used for this purpose should be rejected.

Stone for bridge piers and abutments must not be disintegrated by water action, must be resistant to withstand the abrasion and pounding of logs and floating ice. Near the water level the rock is usually saturated and the pores should be large for relief of pressure in freezing and thawing. The stone should break readily into large blocks of good strength. The Waynesburg and Mahoning sandstones have a high reputation in this state, as bridge stone. Observation on bridges built of this stone, and old culverts shows both of these sandstones to be well adapted to this work.

MICROSCOPICAL EXAMINATION.

The structure and arrangement of the minerals in a coarse grained rock can be examined by aid of a small hand lens, thus determining the kind of rock, size and shape of the particles, approximate amount of pore space, presence of cracks or other defects.

For a more complete study under higher magnifying powers, thin sections of the stone may be made and studied under the compound microscope. This affords a very accurate method of identifying minerals even in the smallest crystals or grains. The structure and mineral components of the fine grained, compact rocks can only be examined in this way, and this method affords the best means of study for the sedimentary rocks. Minerals and structures invisible to the eye when examined in thin sections are clearly seen. Rocks apparently non-crystalline are thus found to be crystalline. Minerals are noted foreign to the essential composition of the rock, some of which by breaking down prove injurious to the strength or color of the rock. Some rocks apparently unbroken, when examined in this way show lines of weakness in form of incipient cracks.

The differences in texture of rocks while visible to the eye, under the microscope show even more clearly. In the microscopic study of the West Virginia sandstones, some were found to be so coarse grained and friable that thin sections could only be made with difficulty and then the particles were broken apart and showed numerous fractures due to the grinding of the specimen. Care is thus required to distinguish between incipient cracks due to the natural breaking down or weathering of the rocks, and therefore defects in the structure, and those fractures resulting from the mechanical grinding of the thin section.

The method of microscopical study of thin sections of building stones is convenient, and can be made at less cost than laboratory tests or chemical analysis. Whether in determining the value of a new building stone, it can entirely take the place of other more expensive tests is very doubtful. For certain desirable determinations, as mineral composition, texture, size and shape of grains, size and number pores, with all the important deductions from these observations, microscopical study is most valuable. Taken in connection with the other methods of examination, the essential properties of strong and durable building stone can be most accurately determined.

Under the microscope some sandstones are seen to be composed of small rounded quartz grains, while in others they are sharp and angular. In some, these grains are variable in size, and in others uniform. The space between the grains variable in size is either open or filled with mineral sometimes quite different from the particles composing the rock. Mica and feldspar can be detected in most of the specimens and in many are grains of iron oxide which influence the color.

In the limestone traces of fossils are found in rock regarded as non-fossiliferous. Mineral impurities also occur, and crystals of calcite are numerous even in so-called noncrystalline limestones. The structure of the dolomite is seen to be quite different from the ordinary limestone. In the

specimens examined it is usually more crystalline and also more porous.

A considerable number of the building stones of the state were studied in thin section, and the results of this examination are given under the descriptions of those rocks.

CHEMICAL ANALYSIS.

Chemical analysis of a rock separates it into its elements. The quantity of silica, alumina, lime, magnesium, iron, etc., in the rock is thus determined. The color of a rock depends to a large extent on iron, its amount and kind. By analysis the amount both of ferric and ferrous iron can be determined.

The chemical analysis of building stone is regarded as less valuable than physical tests or even microscopical examination, yet it serves a useful purpose in the determination of the purity of the rock, the kind and amount to some extent of the impurities, and throws light on the permanency of the color and durability of the rock. A number of the building stones of the state have been analyzed in the Survey laboratory and the results given in the report. The methods of analysis used were the usual ones for rock analysis, following mainly the work of the U. S. Geological Survey.

PHYSICAL TESTS.

By means of certain physical tests, an attempt is made in the laboratory to subject the stone to stresses and destructive forces similar in kind to those which act naturally on the stone in buildings; or in other words, to estimate its strength and durability. To compensate the *time* interval involved in strength and durability of stone structures, the tests are intensified in degree. The results of such tests are regarded as reliable in estimating the characters of the stone in actual use. There may result considerable difference of opinion as to the relative value of the different tests. Some would regard certain tests as far more valuable than others.

The tests are usually made on cubes and prisms or slabs,

which may differ in size in different laboratories. In the present work, the state was fortunate in securing the co-operation of the U. S. War Department and U. S. Geological Survey, so that all the tests were made at the Government Arsenal at Watertown, Massachusetts, and the St. Louis testing plant of the U. S. Geological Survey.

A special effort was made to include all the quarries of the state, but not all responded to repeated invitations to furnish material for these tests. The tests were made on 4 inch cubes, and slabs or prisms 4x6x24 inches. The results of the tests are given in chapter XXVI.

The following tests on West Virginia building stone were made:

1. Compression or crushing.
2. Transverse strength.
3. Shearing strength.
4. Elasticity.
5. Effects of wide variations in temperature.
6. Coefficient of expansion.
7. Porosity.
8. Specific gravity.
9. Weight per cubic foot.
10. Effects of freezing.
11. Fire resistance.
12. Effects of acid fumes.

1. Compression or Crushing Tests.

The crushing strength of building stone expressed in pounds per square inch has long been a popular test in determining the quality of stone. Where only one test is made, this is the one selected, and it is often included in building specifications. The crushing test alone does not throw much light on the quality or durability of a given stone, but taken in combination with other tests it serves a useful purpose.

In the Washington monument, 555½ feet high, the stone at the base is calculated to sustain a maximum pressure of 22,658 tons per square foot, or 314.6 pounds per square inch.

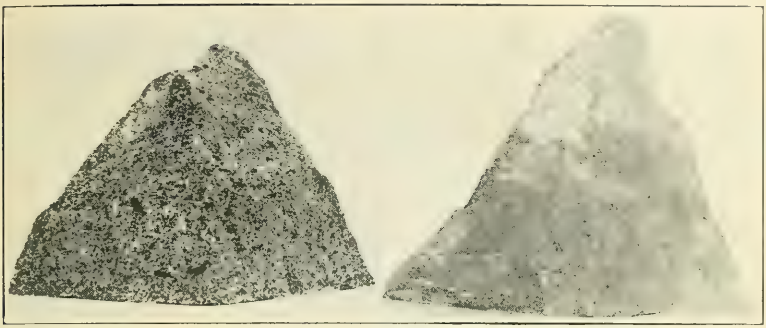

Plate XXIV.—A.—Residual Pyramids after Crushing Tests on West Virginia Sandstones.

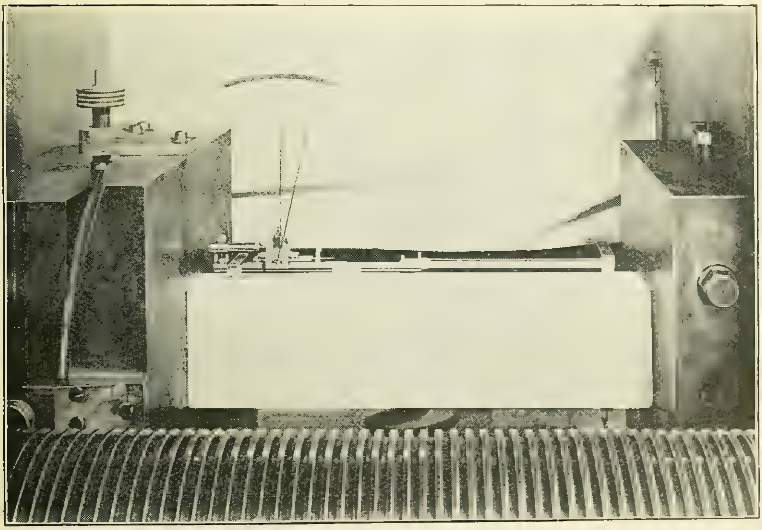

Plate XXIV.—B.—Apparatus for Determining Compressive Elastic Properties of West Virginia Sandstone at the U. S. Arsenal.

If the factor of safety be taken as 20 times the pressure to which the stone is actually subjected, the stone at the base of this monument should withstand a pressure of 6,292 pounds per square inch.[1]

Most buildings are of far less height, so the required pressure would be much smaller. Buckley estimates the maximum pressure in ordinary buildings as about 157.3 pounds to the square inch or with the above factor of safety would require a crushing strength of 3,146 pounds to the square inch; or taking into consideration, unequal pressure and strains, he regards 5,000 pounds to the square inch as sufficient for all ordinary buildings. As shown by tests 5,000 pounds to square inch would be a low strength for most building stones.

For the compression tests, four inch cubes were dressed smooth at the quarry and the work completed on a rubbing bed so as to make the surface as smooth as possible. The compressed faces were coated with a thin layer of plaster of Paris to secure an even distribution of the compression loads over the material. Plate XXIV-A shows form of pyramids resulting from compression of two West Virginia sandstones. The following comments on these tests are given in the U. S. Arsenal report on Tests of Metals, etc., for 1894 (p. 376):

"In the details of the tests is found a column in which is recorded the load under which the specimen developed its first crack. The time when this first crack appeared differed considerably with different stones. With some stones cracks began to develop at one-fourth of the ultimate resistance, while with others there was no warning of impending rupture. Simultaneously with the first crack came complete rupture.

Generally stones which commence to develop cracks early are characterized by their frequent recurrence as the loads are increased and approach the ultimate strength, when an explosive failure occurs in the case of hard rocks, a more gradual fracture taking place with the softer stones."

The following table illustrates the compression tests on

1. Buckley, Mo. Geol. Survey (Series 2), vol. II, p. 39.

a number of rocks from different localities and may be used for comparison with the tests on West Virginia building stones given later in this report:

LOCALITY	First Crack Pounds	Ultimate Strength	
		Total Pounds	Per Sq. In. Pounds
Milford, Mass., granite[2]	263,000	417,400	25,451
Georgia, marble[2]	188,200	188,200	11,532
Worcester, Mass., sandstone[2]	154,500	154,500	9,656
Olymphia, Oregon, sandstone[2]	195,000	197,800	12,061
Junction City, Kansas, limestone[3]	51,000	51,600	3,350
Jasper, Alabama, sandstone[2]	265,900	265,900	16,570
Redfield, Kansas, sandstone[3]	134,800	134,800	8,446
Little Rock, Arkansas, sandstone[3]	108,000	289,600	17,921

2. TRANSVERSE TEST.

In order to determine the strength of stone for caps, sills and arches, it is important to determine the transverse or cross breaking strength. This is an important test often omitted, but stone is sometimes found with good compression and low transverse strength. Such stone suitable for ordinary building construction, would have a low value for work when the stone is supported at the ends and weight applied near the center. Usually too little attention is given the strength of stone for such uses, the stone being selected for color or low cost. It would be better if more attention was given in buildings to the transverse strength of stone caps, etc.

The stone for this test was cut in the form of slabs or prisms 4x6x24 inches. These were made even and smooth on a rubbing bed and rested on end supports 19 inches apart, then loaded at the middle over a bearing one inch wide, the load increased until the slab was broken (see figure 14).

2. U. S. Arsenal, Tests of Metals, etc., 1894, pp. 387, 389.
3. U. S. Arsenal, Tests of Metals, etc., 1895.

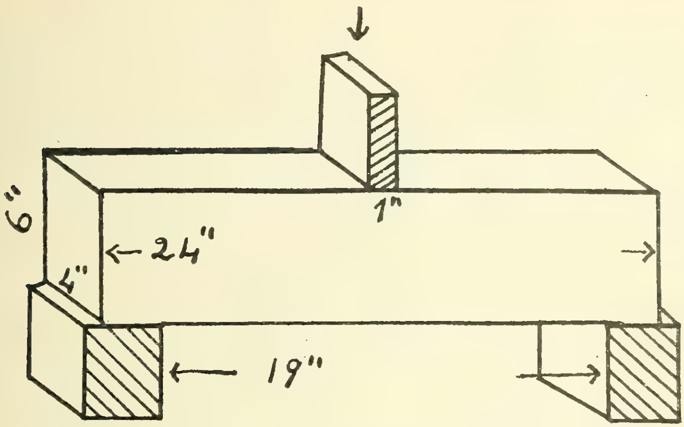

Fig. 14. Diagram showing arrangement of stone prism for transverse strength determination.

The modulus of rupture was obtained from the following formula:[4]

$$W = \frac{2\ b\ d^2}{3\ L}\ R \quad \text{from which}$$

$$R = \frac{3\ L}{2\ b\ d^2}\ W$$

W=concentrated load at center in pounds.
B=breadth in inches.
D=depth in inches.
L=length in inches.
R=modulus of rupture in pounds per square inch.

The following table shows the results of some of the transverse tests made at the U. S. Arsenal:

4. Buckley, Wisc. Geol. Survey, Bull. IV, p. 62.

LOCALITY	Distance between end Supports Inches	Breadth Inches	Depth Inches	Ultimate Strength	
				Total Pounds	Modulus of rupture Pounds
Milford, Mass. granite	19	4.03	6.03	9,020	1,745
Rockport, Mass. granite	19	4.03	6.02	12,320	2,404
Dekalb, N. Y. marble	20	3.91	6.04	5,440	1,144
Junction City, Kansas, limestone	20	4.10	6.15	2,730	528
Jasper, Alabama, sandstone	20	4.01	6.01	9,120	1,889
Little Rock, Ark. sandstone	20	4.05	6.03	11,990	2,442
Redfield, Kansas, sandstone	20	4.00	6.01	10,060	2,088
Olymphia, Wash. sandstone	20	4.04	6.05	10,220	2,073
Roseburg, Oregon, sandstone	20	4.21	6.10	3,780	724

3. Shearing Strength.

The shearing strength on stone is due to a thrusting or pushing rather than a perpendicular pressure. Stone in a building which settles unevenly may be subject to such movemens causing the stone to crack or break.

In making this test, the stone prism rests upon blocks 6 inches apart, and the pressure applied by a plunger having a face 5 inches wide, which gives a half inch space clear on each side the plunger, as shown in figure 15.

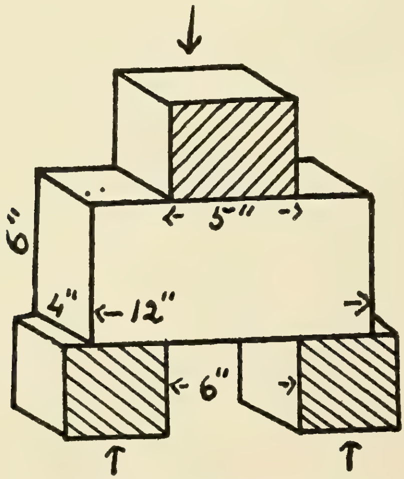

Fig. 15. Diagram showing arrangement of stone prism for shearing strength determination.

In the tests at the U. S. Arsenal, it was found that, "before the shearing strength was reached tension fractures were developed on the under side of the stone midway the 6-inch free space, and there were instances in which longitudinal fractures opened in the ends of the stones, corresponding to shearing along the grain in the tests of timber. These fractures occurred first, the direct shearing fractures being the final ones. Modifications in the arrangement of the supporting blocks were made and endwise movement of the stone restricted by firmly securing steel blocks abutting against the ends of the stone. The manner of failure and order of fractures, however, remain as in the first instance."

In the following table are given a few of the shearing strength tests made at the U. S. Arsenal:

LOCALITY	Shearing Area Square In.	Transverse fracture developed on tension side Pounds	Shearing Strength		Surface Sheared
			Total	Per Square inch	
Milford, Mass. granite[5]	48.48	24,800	108,400	2,236	1
Marble Hill, Ga., marble[5]	48.24	30,300	72,400	1,501	1
Douglas Co., Ore., sandstone[5]	49.00	22,500	89,700	1,831	2
Mt. Vernon, Ky., limestone[5]	49.20	25,800	99,200	2,016	2
Jasper, Ala., sandstone[6]	48.36	52,600	106,500	2,202	1
Redfield, Kansas, sandstone[6]	47.76	31,500	92,700	1,940	1
Olymphia, Wash., sandstone[6]	48.04	27,500	75,100	1,563	1
Little Rock, Ark., sandstone[6]	47.00	35,600	119,800	2,549	2

4. Elasticity.

Tests are sometimes made to determine the elasticity of stone under compression. The prisms 4x6x24 inches are placed under compression, loads applied parallel to the direction of the long sides, and the compressibility measured by

5. Tests of Metals, etc., p. 426, 427; 1894.
6. Tests of Metals, etc., 1895.

a micrometer which covers a gauged length of 20 inches on the prism (see figure 16).

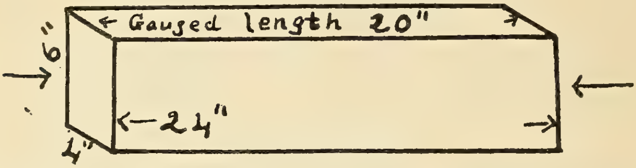

Fig 16. Form of prism for determination of elasticity of stone.

The following remarks are made on this test in the U. S. Arsenal report for 1894 (p. 377): "Micrometer observations were made under different loads, beginning with an initial load of 100 pounds per square inch. Permanent sets were determined at intervals, and the behavior of the stones noted while under reduced and repeated stresses. Stones have a variable modulus of elasticity, the rigidity generally increasing with the stresses. Plate XXIV-B shows the instrument used at the U. S. Arsenal for the determination of elasticity of stone prisms.

"Two values of the modulus are computed and entered in the tabulation of the results. The first value is taken between two lower loads, the second between two higher loads, not, however, in the latter case very closely approaching the compressive strength of the material. * * * * * No cases of recovery of stone samples have yet been met, although observations have not extended over so wide an interval of time with this material as in the case of experiments with iron and steel bars.

"Following the measurements of the longitudinal compressibility of the stones, the micrometer was placed on the samples transversely and the lateral expansion determined.. The ratio of lateral expansion to longitudinal extension or compression in the case of steel has been found to be nearly 1÷3.55. Some of these stones have a higher ratio than the steel, while on the other hand the ratio is much smaller with some stones, being only 1-11 for the Cooper sandstone.

Some of the results of these tests at the U. S. Arsenal are given in the following table:

LOCALITY	APPLIED LOADS		In Gauged Length 20 in.	
	Total Pounds	Per Sq. In. Pounds	Compression Inch	Set Inch
Milford, Mass., granite.........	95,760	4,000	0.0112	.0009
Milford, Mass., granite.........	215,460	9,000	0.0229	.0015
Mt. Vernon, Ky., limestone.....	9,972	400	0.0023	....
Mt. Vernon, Ky., limestone.....	49,860	2,000	0.0155	.0034
E. Longmeadow, Mass., sandstone	4,820	200	0.0049	....
E. Longmeadow, Mass., sandstone	48,200	2,000	0.0328	....
Fort Smith, Ark., sandstone....	27,110	1,000	0.0070	....
Fort Smith, Ark., sandstone....	108,440	4,000	0.0300	....

5. Effects of Wide Variations in Temperature.

The expansion and contraction of stone under changes of temperature may develop minor cracks and lines of weakness later enlarged by freezing and thawing of moisture and so seriously injure the strength of the stone. According to experiments made in 1832 by Col. Totten,[7] a block of stone one foot long raised from a temperature of freezing (32°) to that of a hot summer day (90°) would be expanded to the amount of .005416 inch or would be 12.005416 inches long.

Tests to determine the expansion and contraction of stone under wide ranges of temperature are made in the following way at the U. S. Arsenal (Test Metals 1894, p. 378):

"The transverse specimens were prepared with small plugs in one face, 20 inches apart, which were drilled and countersunk for the purpose of establishing a definite guaged length which could be subsequently measured while the stones were immersed in cold and hot water baths and in hot air tank, and while in these baths their gauged lengths were measured. A reference bar for comparison of length was kept at all times in the cold water bath, near the temperature

7. Quoted Md. Geol. Survey, Vol. II, p. 109.

of the melting point of ice. The reference bar had drilled and countersunk holes 20 inches apart similar to the stones."

The measurements were made with a mounted and protected micrometer, and a comparison of readings on stone and test bar in bath with temperature of 32° showed the results to be very accurate, with a greater variation in the hot water and air baths, due especially to the effect of alternate cold and hot exposures of the micrometer but the final results are regarded as falling within a limit of error of less than one-thousandth of an inch. The specimens tested show a slight increase in size or swelling and after treatment this swelling appears to be permanent.

The following tests from the U. S. Arsenal report (1894, No. 19) show the conditions and effects on a prism of sandstone from Olymphia, Washington:

TREATMENT	TIME	TEMPERATURE	EXPANSION
Open air................		80°	
Storage tank, water.....	9 days	73°	.0082 inch
Cold water..............	7 hours	34°	.0069 "
Hot water...............	10 hours	212°	.0218 "
Cooled in water.........	16 hours	83°	.0133 "
Cold water.............	24 hours	34°	.0104 "

It was noted in the experiments that there was a permanent swelling in the stone when passed from cold water bath (32° F.) through the hot water bath (212° F.) and back again to the cold water temperature of 32° F. The following table from the report of 1895 (p. f23) shows the effect on sandstones:

Sandstone.	Amount of permanent swelling. Inch.
From Cromwell, Conn	.0067
From Worcester quarry, East Longmeadow, Mass	.0022
From Kibbe quarry, East Longmeadow, Mass	.0029
From Kettle River quarry, Minnesota	.0018
From Cabin Creek quarry, Johnson Co., Ark	.0018
From Sebastian County, Ark	.0015
From Bourbon County, Kansas	.0017
From Alameda County, California	.0174
From Olymphia, Washington	.0035
From Thurston County, Washington	.0148 / .0035
Mean	.0047

6. Coefficient of Expansion.

The coefficient of expansion or ratio of increase in length for one degree temperature to the length at O° is determined by the formula,

$$A=\frac{B-L}{L\ T}$$

Where A=coefficient of expansion.
L=gauged length of prism.
B=length at temperature T°.
T=temperature.

7. Porosity.

The object of this test is to determine the amount of water a given stone will absorb when immersed in water. The stones which absorb a considerable percentage of water are regarded as less durable than those of low absorption, on account of the danger of freezing and thawing. Dr. E. R. Buckley in his report on Wisconsin building stones (p. 373) comments on this subject as follows: "It has been customary to look with suspicion upon a rock which absorbs more than one-tenth of its weight of water. But it has been previously shown that the danger from freezing and thawing is not so

much dependent upon the percentage of water absorbed as upon the size of the pores in a rock. A rock may have a ratio of absorption of 15 per cent or even 18 per cent and yet never be in danger of freezing on account of the rapidity with which it gives off its included water. The amount of water which a rock will absorb has very little relation to the liability of injury from freezing and thawing, in the case of building stone."

Buckley thus regarded porosity of a stone as far more important to determine than the amount of water absorbed or ratio of absorption. His method of determination of porosity is as follows[8]: "The dry and saturated weights obtained for the samples used in computing the specific gravity, were used. The difference in these weights was multiplied by the specific gravity of the rock. This amount was added to the dry weight giving the sum. The difference of the dry and saturated weights multiplied by the specific gravity of the rock, was then divided by the sum. This last result is the actual percentage of pore space compared with the volume of the sample tested."

The ratio of absorption is determined by thoroughly drying cubes of the rock and weighing them, and then covering them with water for 48 to 96 hours. After the stone is fully saturated it is removed and the excess water removed from the surface of the cube by blotting paper, and weighing. The increase in weight is due to the water absorbed and the ratio of absorption computed.

The following table from Buckley's report (Table V) shows the porosity and ratio of absorption of some of the Wisconsin building stones:

	Porosity.	Ratio of Absorption.
Amberg granite	.108	.040
Montello granite	.208	.079
Bridgeport limestone	13.02	5.46
Washington limestone	0.55	0.20
Port Wing sandstone	21.41	10.33
Dunnville sandstone	28.24	15.13
Washburn sandstone	19.59	9.01

8. *Loc. cit.* p. 69.

8. Specific Gravity.

The density of a body is measured by its specific gravity, which represents the weight of a substance compared with an equal volume of water. It is a useful property in comparing relative weights of bodies. The volume of a solid may be determined by weighing it in the air and then in water, the difference in weight being the weight of the volume of water displaced, which volume is equal to that of the solid. The weight of the substance divided by its volume is the *specific gravity* of the substance.

The difficulties involved in the accurate determination of specific gravity are first, the complete removal of all water from the pores of the rock in drying; second, the complete saturation of the specimen and removal of air bubbles in the pore spaces.

Buckley[9] found in his experiments that all the water was not removed when the rock cubes were heated to 100° C, but that a temperature of 110° C was necessary. He further found that when the dried block was quickly immersed in water, the water passing into the stone from all directions enclosed small air bubbles which could only be expelled with great difficulty. He slowly immersed the cubes in boiling water, from bottom to the top, under the receiver of an air pump in which the pressure was maintained for 72 hours at less than 1-10 of an atmosphere.

Buckley's determination of specific gravity of a number of building stones is given below:

Berlin granite	2.64
Montello granite	2.64
Bridgeport limestone	2.74
Washington limestone	2.82
Duluth brown sandstone	2.62
Grover red sandstone	2.64
Washburn sandstone	2.64

9. *Loc. cit.*, p. 65.

9. Weight Per Cubic Foot.

The weight of a cubic foot of stone is usually determined by multiplying the weight of a cubic foot of water (62.5 pounds) by the specific gravity of the stone. The weight of a cubic foot of the Washburn sandstone above, by this method would be 62.5x2.64 or 165 pounds. Most determination of weight of rocks are made in this way, but Buckley points out that such weights will vary for the same rock made from time to time, on account of the variation in quantity of interstitial water. He states (p. 69) that the weight of a cubic foot of stone will not only depend on specific gravity, but also on amount of pore space and water content. With these modifying factors, the correct weight of a cubic foot of stone should be of a dry stone free from all water.

To obtain this correct weight Buckley deducts from the above determination of ordinary weight of the stone (Weight of a cubic foot of water multiplied by specific gravity), the weight of a quantity of stone of same specific gravity equal in volume to the percentage of pore space in the stone. He thus determines the weight of the Washburn sandstone with its 10.59 per cent porosity to be 132.63 pounds instead of the ordinary determination of 165 pounds.

The specific gravity of the following rocks were determined by the Maryland Geological Survey (Vol. II, p. 105), and the weights per cubic foot are added as determined by the usual method:

	Spec. Grav.	Wgt. per cubic ft.
Marble, close grained, Md..........	2.83	176.87
Marble, blue, Md....................	2.61	163
Sandstone, Seneca, Md.............	2.67	166.87
Sandstone, Little Falls, N. J........	2.48	155
Sandstone, coarse, Nova Scotia.....	2.51	156.87
Granite, Port Deposit, Md..........	2.61	163
Limestone, blue, Penn..............	2.70	168.75

10. Effects of Freezing and Thawing.

One of the most important agencies in the disintegration of rocks through weathering is freezing and thawing of included moisture. The higher the ratio of absorption in rocks, the greater the amount of water which may be held in the rock, but not always is there a greater increase in destructive effects on the rock, since the number and size of the pores must be considered. A porous rock with large pores would hold more moisture, but in freezing there would be more room for expansion in the rock itself and also through these pores to the surface.

Water passing from the liquid to the solid state of ice expands in proportion of 100 to 109, or in other words 100 cubic inches of water on freezing would require a space of 109 cubic inches in form of ice, thus exerting a pressure of 150 tons to each square inch of surface.[10] Building stone with its absorbed water at freezing temperature is thus exposed to great stress which may cause it to crumble and break. It is therefore important in the selection of durable stone to determine its resistance to freezing and thawing.

A number of methods have been devised to make these tests in the laboratory. In the method formerly used, the stone was saturated with a solution of sulphate of soda which on crystallizing expands similar to water freezing into ice.[11] It was found that this salt exerted a chemical action on the stone, making it weaker and so making the loss in strength greater than in the natural process of freezing.

The method now generally employed in freezing tests is to use one or two inch cubes which are carefully dried and weighed, then saturated in distilled water and placed outdoors in the water or in a freezing mixture and allowed to freeze. They are then brought into a warm room, thawed, saturated with water, and frozen again. Buckley in his work on the Wisconsin building stones, repeated this operation daily for 35 days. After this period of time the cubes were thor-

10. Md. Geol. Survey, Vol. II, p. 104.
11. Md. Geol. Survey, Vol. II, p. 104.

oughly dried and weighed, and the loss in weight determined. The cubes after this treatment were crushed to determine their compression strength.

The following table (Nos. VI, VII) from Buckley's report shows the loss in weight and ultimate strength of the frozen and the fresh samples:

Locality	Loss in Weight Grams	Loss Per cent	Ultimate strength lbs. per sq. in.	Ultimnte strength fresh sample
Amberg granite..............	0.08	0 02	10,619	19,988
Marblehead limestone ...	none	none	27,366	41,620
Port Wing sandstone......	0.10	0.037	4,399	5,329
Dunnville sandstone.......	0.37	0.16	3,464	2,722

11. Fire Resistance of Stone.

All building stone will be destroyed in fire when the temperature is extreme, but differences in heat resistance are found in different building stones. Some will spall under comparatively low temperatures while others will pass through ordinary fire with but little damage. Buckley states (loc. cit. p. 72), "Other things being equal, it appears that a rock having a uniform texture and simple mineralogical composition, has the greatest capacity to withstand extreme heat."

The method used by Buckley (p. 73) in testing the fire resistance of rocks was as follows: One and two inch cubes were placed in a muffle furnace, and the temperature gradually increased from 600° to 1,500° F. The visible effects at temperatures between 600° and 1,500° as indicated by a standard pyrometer, were carefully noted. At a temperature of 1,300° to 1,500° F., the specimens were removed from the furnace, and allowed to cool gradually, though a few were suddenly cooled by plunging them into cold water.

From his experiments on the Wisconsin building stone, Buckley reached the following conclusions (p 385): "As a

result of the experiments, it was discovered that all the samples when struck by the hammer or scratched with a nail, after being taken from the muffle furnace, emitted a sound very similar to that which would be given off by a brick. This sound was characteristic not only of the sandstones, but also of the granites and some of the limestones. * * *

"In contrast with the limestone and granite samples, the sandstones were, to all outward appearances, little injured by the extreme heat. The samples which were taken from the muffle furnace and allowed to cool gradually were apparently as perfect as when first placed in the furnace. But after they had cooled, one could crumble any of them in the hand, almost as readily as the softest incoherent sandstone. In fact when they were heated to a temperature of 1500° F., some of the samples had become so incoherent that it was barely possible to pick them up after cooling, without their falling to pieces. * * * One might very easily be deceived regarding the amount of injury occasioned by extreme heat on the coarser grained sandstone. After heating the samples, as a rule, look as fresh and clean as when first quarried, and unless tested with a hammer, one would never suspect that the strength was so largely gone.

"In general, the results of the temperature tests seem to indicate that there are but few, if any stones, whether they be granite, limestone or sandstone, that will effectively withstand the extreme temperature of 1500° F. * * * What actually takes place in a stone when heated is not definitely known, yet it is quite certain that the contraction and expansion of the individual particles, as they are heated and cooled, differ to such an extent that rupture takes place throughout the entire mass of the sample tested. These innumerable ruptures which occur between the particles composing the rock occasion the loss in strength, which makes the rock unfit for further use."

W. E. McCourt[12] in 1905 conducted a series of tests, on New York building stone. He found that at temperature

of 850° C. (1562° F.) all the cubes tested were injured, but they varied widely in extent of damage.

He states that "all the sandtsones which were tested were fine grained and rather compact. All suffered some injury, though, in most cases the cracking was along the lamination planes. In some cubes, however, transverse cracks were also developed. * * * A very porous sandstone will be reduced to sand, and a stone in which the cement is largely limonite or clay will suffer more than one held together by silica or lime carbonate."

At lower temperatures, say not to exceed 550° C. (1022° F.) "all the stones will stand up very well, but at the temperature which is probable in a conflagration, in a general way, the finer grained and more compact the stone and the simpler in mineralogic composition the better will it resist the effect of the extreme heat. The order, then, of the refractoriness of the New York stones which were tested might be placed as sandstone, fine grained granite, limestone, coarse grained granite, gneiss, and marble."

12. Effects of Acid Fumes.

Some building stones in cities are altered by the action of gases in the air, especially carbonic dioxide and sulphurous acid, which are carried into the atmosphere with smoke from factory and house fires. The effect may prove injurious to the color and durability of limestones or rocks with calcareous cement.

Buckley used the following method (**loc. cit.**, p. 7[?]) in testing the effects of acid fumes on the Wisconsin stone: Two large mouthed bottles were obtained and in the bottom were placed several smaller bottles containing water to keep the atmosphere moist. The small samples (1 to 1½ inch cubes) were dried at a temperature of 110° C., and weighed. They were then placed in the large mouthed bottles and the corks were carefully sealed. Through each of the corks were passed two small glass tubes, to the end of which rubber tub-

12. New York State Museum, Bull. 100; 1906.

ing was attached. Washed carbon dioxide was then passed into one of the bottles, and washed sulphur dioxide into the other. After the bottles had been filled with carbon dioxide and sulphur dioxide, respectively, the tubing was closed by means of pinch cocks. The carbon dioxide and sulphur dioxide were each renewed about twice a week through a period of six weeks. The samples were then removed, washed in cold distilled water, heated at 110° C., until all the included water was driven off and finally weighed.

CHAPTER XXVI.

PHYSICAL TESTS ON WEST VIRGINIA SANDSTONES.

It was the plan of this report to include in the present chapter a very complete series of tests on the sandstones of the state. This work was started over a year ago at the Watertown Arsenal of the United States War Department, but later by act of Congress this testing plant was ordered moved to Washington, and the work on these sandstones was stopped. The material was then sent to the testing laboratory of the United States Geological Survey at St. Louis, and again by removal of this plant to Pittsburg the work has been interrupted. As it will be several months before the tests can be completed it was decided best not to further delay the issue of this volume, and to publish the incomplete tests in this chapter. The complete tests will appear in a later bulletin of the Survey.

The character and objects of these tests are discussed in the preceding chapter, and the results of the work to date are given below. Unless otherwise stated the tests were made by the United States Geological Survey.

C. B. CONOWAY SANDSTONE QUARRY.

From C. B. Conoway quarry near Barracksville, Marion County—Geological horizon—Waynesburg Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.00 x 3.96	3.90	8,770	1,520,000
4.00 x 4.00	3.96	8,210	1,250,000
4.03 x 3.95	3.88	7,440	
Average		8,140	1,390,000

Transverse Test.

Breadth. Inches.	Depth. Inches.	Span. Inches.	Modulus of Rupture. Pounds.
5.98	4.00	20	570
6.06	4.14	20	600
6.05	3.98	20	480
Average			550

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	3.45	3.74	3.78	8.00	8.67	8.77
	3.19	3.60	3.69	7.40	8.36	8.55
	2.97	3.48	3.54	6.89	8.07	8.21
Average	3.20	3.61	3.67	7.43	8.37	8.51

Shearing Test.

Lateral Dimensions. Inches.	Loaded Length. Inches.	Ultimate Strength Pounds.
2.15 x 2.12	2	1,010
2.16 x 2.13	2	1,490
2.29 x 2.16	2	1,310
Average		1,270

Freezing Test.

(Compression Strength After 10 Freezings.)

Lateral Dimensions. Inches.	Height. Inches.	Ultimate Strength. Pounds.	Modulus of Elasticity
4.10 x 4.10	3.92	8,020	2,000,000
4.08 x 4.09	3.80	8,150	1,600,000
4.09 x 4.11	3.84	7,780	1,030,000
Average		7,980	1,540,000

Absolute porosity	12.85
Per cent. pore space filled at end of 48 hours	66.2
True specific gravity	2.661
Apparent specific gravity	2.319
Weight per cubic foot	144.6 lbs.

FAY WATSON SANDSTONE QUARRY.

From J. Fay Watson quarry at Fairmont—Geological horizon—Sewickley Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.02 x 4.04	3.96	10,680	1,480,000
4.03 x 4.00	3.83	11,470	1,850,000
4.05 x 4.10	3.92	12,760	1,950,000
Average		11,640	1,760,000

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.01	4.00	20	1,910
6.04	4.02	20	1,740
6.02	3.99	20	1,840
Average			1,830

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	0.58	2.71	2.91	1.43	6.66	7.17
	0.47	2.36	2.67	1.17	5.83	6.60
	0.55	2.41	2.71	1.37	5.93	6.69
Average	0.55	2.49	2.76	1.32	6.14	6.82

Shearing Test.

Lateral Dimensions. *Inches.*	Loaded Length. *Inches.*	Ultimate Strength *Pounds.*
2.10 x 2.02	2	2,130
2.03 x 2.08	2	1,830
2.08 x 2.10	2	2,070
Average		2,010

Freezing Test.

(Compression Strength after 10 Freezings.)

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.08 x 4.07	3.92	14,690	1,340,000
4.09 x 4.09	3.98	.....	1,660,000
4.05 x 4.03	3.86	.....	1,440.000
Average			1,480,000

Absolute porosity	9.04
Per cent. pore space filled at end 48 hours	75.4
True specific gravity	2.710
Apparent specific gravity	2.465
Weight per cubic foot	153.7 lbs.

C. S. RIGGS SANDSTONE QUARRY.

From C. S. Riggs quarry at Fairmont—Geological horizon—Upper Pittsburg Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.08 x 4.10	3.84	12,850	1,540,000
4.05 x 4.10	3.92	12,220	1,540.000
4.05 x 4.15	3.91	11,990	1,340,000
Average		12,350	1,470,000

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.07	3.99	20	910
5.65	4.00	20	980
6.05	3.99	20	...
Average			950

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	0.68	1.90	1.94	1.74	4.86	4.96
	0.78	2.05	2.08	1.98	5.21	5.31
	0.79	2.00	2.07	2.02	5.08	5.27
Average	0.75	1.98	2.03	1.91	5.05	5.18

Shearing Test.

Lateral Dimensions. *Inches.*	Loaded Length. *Inches.*	Ultimate Strength *Pounds.*
2.16 x 2.15	2	1,450
2.20 x 2.21	2	1,210
2.15 x 2.16	2	1.800
Average		1,490

Freezing Test.

(Compression Strength after 10 Freezings.)

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.13 x 4.15	3.90	13,000	1,500,000
4.11 x 4.13	3.93	13,000	1,940,000
4.14 x 4.14	3.90	12,850	1,430,000
Average		12,950	1,620,000

Absolute porosity	6.25
Per cent. pore space filled at end 48 hours.......	82.9
True specific gravity	2.720
Apparent specific gravity......................	2.550
Weight per cubic foot	159.0 lbs.

MICHAEL NAUGHTON SANDSTONE QUARRY.

From Michael Naughton quarry at Cornwallis, Ritchie County—Geological horizon—Waynesburg Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
3.83 x 4.03	3.92	3,500	450,000
3.98 x 3.96	4.00	3,460	440,000
3.92 x 3.93	3.84	3,430	310,000
Average.................		3,460	400,000

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
5.90	3.95	20	270
5.96	3.95	20	330
5.94	4.01	20	270
Average.......................			290

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours.
	5.40	5.65	5.74	11.96	12.50	12.69
	5.59	5.82	5.87	12.33	12.85	12.94
	5.60	5.81	5.90	12.27	12.73	12.93
Average	5.53	5.76	5.84	12.19	12.69	12.85

Shearing Test.

Lateral Dimensions. *Inches.*	Loaded Length. *Inches.*	Ultimate Strength *Pounds.*
2.19 x 2.15	2	650
2.12 x 2.15	2	590
2.12 x 2.19	2	390
Average..........................		540

Freezing Test.

(Compression Strength after 10 Freezings.)

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.12 x 4.13	3.76	3,780	480,000
4.11 x 4.12	3.94	4,140	500,000
4.12 x 4.15	3.98	4,250	455,000
Average.................		4,060	478,000

Absolute porosity	17.43
Per cent. pore space filled at end 48 hours.......	73.7
True specific gravity............................	2.668
Apparent specific gravity.......................	2.203
Weight per cubic foot...........................	137.4 lbs.

SATTES SANDSTONE QUARRY.

From F. A. Sattes quarry at Sattes, Kanawha County, opposite St. Albans—Geological horizon—St. Albans Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.04 x 4.08	3.99	9,940	1,290,000
4.00 x 4.00	3.94	12,500	1,400,000
4.10 x 4.05	3.93	12,380	1,450,000
Average.................		11,610	1,380,000

Transverse Test.

Breadth. Inches.	Depth. Inches.	Span. Inches.	Modulus of Rupture. Pounds.
6.06	4.04	20	1,010
6.10	4.00	20	760
6.04	4.06	20	680
Average			820

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	3.69	4.57	4.69	8.59	10.64	10.93
	3.32	4.58	4.66	7.70	10.61	10.82
	3.55	4.65	4.73	8.21	10.76	10.94
Average	3.52	4.60	4.69	8.17	10.67	10.90

Shearing Test.

Lateral Dimensions. Inches.	Loaded Length. Inches.	Ultimate Strength Pounds.
2.16 x 2.14	2	1,520
2.12 x 2.16	2	1,410
2.06 x 2.12	2	1,320
Average		1,420

Freezing Test.

(Compression Strength After 10 Freezings.)

Lateral Dimensions. Inches.	Height. Inches.	Ultimate Strength. Pounds.	Modulus of Elasticity
4.14 x 4.14	4.00	9,000	1,500,000
4.13 x 4.14	3.96	9,000	1,030,000
4.14 x 4.14	3.97	8,400	1,200,000
Average		8,800	1,240.000

Absolute porosity	14.16	
Per cent. pore space filled at end 48 hours	76.4	
True specific gravity	2.707	
Apparent specific gravity	2.321	
Weight per cubic foot	144.7	lbs.

T. M. JACKSON SANDSTONE QUARRY.

From T. Moore Jackson quarry at Clarksburg—Geological horizon—Uniontown Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.03 x 4.07	4.02	12,500	2,400,000
4.01 x 4.05	4.03	11,490	1,780,000
4.06 x 4.04	4.05	11,260	1,800,000
Average		11,750	1,990,000

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.05	4.11	20	1,020
6.10	4.10	20	1,160
6.15	4.08	20	1,280
Average			1,150

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	1.38	3.37	3.37	3.35	8.20	8.22
	1.28	3.33	3.33	3.11	8.11	8.11
	1.25	3.24	3.26	3.04	7.89	7.93
Average	1.30	3.31	3.32	3.17	8.07	8.09

Shearing Test.

Lateral Dimensions. *Inches.*	Loaded Length. *Inches.*	Ultimate Strength *Pounds.*
2.16 x 2.15	2	1,340
2.20 x 2.21	2	1,650
2.15 x 2.21	2	1,840
Average...........................		1,610

Freezing Test.

(Compression Strength after 10 Freezings.)

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.19 x 4.16	4.26	.....	2,160,000
4.11 x 4.26	4.19	11,440	1,370,000
4.16 x 4.08	4.11	.....	2,000,000
Average.................			1,840,000

Absolute porosity	10.05
Per cent. pore space filled at end of 48 hours....	80.5
True specific gravity..........................	2.707
Apparent specific gravity......................	2.435
Weight per cubic foot..........................	151.9 lbs.

STORER SANDSTONE QUARRY.

From J. P. Storer quarry near Rowlesburg, Preston County.—Geological horizon—Mauch Chunk Sandstone.

Compression Test.

Lateral Dimensions. *Inches.*	Height. *Inches.*	Ultimate Strength. *Pounds.*	Modulus of Elasticity
4.06 x 4.11	3.91	....	1,950,000
4.14 x 4.03	4.00	....	1,400,000
4.16 x 4.13	4.00	....	1,980,000
Average.................		....	1,780,000

Transverse Test.

Breadth.	Depth.	Span.	Modulus of Rupture.
Inches.	*Inches.*	*Inches.*	*Pounds.*
6.09	4.05	20	2,130
6.08	4.06	20	2,300
Average			2,220

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours.
	0.25	1.33	1.63	0.62	3.38	4.14
	0.21	1.12	1.40	0.53	2.85	3.56
	0.24	1.37	1.68	0.61	3.48	4.26
Average	0.23	1.27	1.57	0.59	3.24	3.99

Shearing Test.

Lateral Dimensions.	Loaded Length.	Ultimate Strength
Inches.	*Inches.*	*Pounds.*
2.20 x 2.21	2	1,590
2.23 x 2.19	2	2,610
2.14 x 2.16	2	2,420
Average		2,310

Apparent specific gravity........................ 2.538
Weight per cubic foot........................... 158.2 lbs.

CHAS. STOZENFELS SANDSTONE QUARRY.

From Chas. Stozenfel's quarry at Grafton.—Geological horizon—Buffalo Sandstone.

Transverse Test.

Breadth.	Depth.	Span.	Modulus of Rupture.
Inches.	*Inches.*	*Inches.*	*Pounds.*
6.00	4.08	20	810
6.00	4.10	20	810
6.00	4.05	20	780
Average			800

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	3.92	4.03	4.10	8.92	9.18	9.34
	5.05	5.09	5.09	11.49	11.58	11.58
	5.25	5.27	5.32	11.90	11.94	12.06
Average	4.74	4.80	4.84	10.77	10.90	10.99

Apparent specific gravity...................... 2.274
Weight per cubic foot............. .... 141.8 lbs.

PRESTON BLUE STONE COMPANY.

A green sandstone from Preston Blue Stone Company quarry at Rowlesburg, Preston county, at Rowlesburg Sandstone horizon.

Transverse Test.

Breadth.	Depth.	Span.	Modulus of Rupture.
Inches.	*Inches.*	*Inches.*	*Pounds.*
6.00	4.17	20	2,345
6.10	4.18	20	2,599
6.15	4.21	20	2,541
Average			2,495

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	0.24	1.31	1.52	0.62	3.36	3.90
	0.26	1.26	1.47	0.68	3.24	3.77
	0.42	1.92	2.04	1.07	4.85	5.16
Average	0.34	1.50	1.68	0.79	3.82	4.28

Apparent specific gravity...................... 2.557
Weight per cubic foot........................ 159.4 lbs.

CHRISTIAN SANDSTONE QUARRY.

Buffalo Sandstone at Morgantown.

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.12	4.10	20	1,490
6.05	4.00	20	1,218
5.88	3.98	20	1,190
Average			1,299

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	1.40	2.68	2.68	3.59	6.60	6.60
	1.40	2.84	2.86	3.43	6.94	6.98
	1.70	3.12	3.13	4.16	7.62	7.64
Average	1.52	2.88	2.89	3.73	7.05	7.07

Apparent specific gravty...................... 2.452
Weight per cubic foot........................ 152.9 lbs.

GASTON SANDSTONE QUARRY.

From Wm. Gaston quarry at Morgantown.—Geological horizon—Morgantown Sandstone.

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
5.95	4.04	20	1,050
6.00	4.00	20	980
6.00	4.05	20	1,110
Average			1,047

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	2.14	3.77	3.77	5.14	9.06	9.06
	1.99	3.66	3.66	4.80	8.81	8.81
	2.30	3.79	3.81	5.52	9.10	9.15
Average	2.14	3.74	3.75	5.15	8.99	9.01

Apparent specific gravity........................ 2.404

Weight per cubic foot........................ 149.9 lbs.

WILLIAM COX SANDSTONE QUARRY.

From Wm. Cox quarry at Morgantown.—Geological horizon—Connellsville Sandstone.

Transverse Test.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.10	3.89	20	510
6.00	4.01	20	620
6.00	4.02	20	720
Average			617

Ratio of Absorption.

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours.
	4.50	4.54	4.55	10.25	10.36	10.38
	3.58	3.58	3.67	8.07	8.07	8.29
	4.37	4.37	4.45	9.99	9.99	10.16
Average	4.15	4.16	4.22	9.44	9.47	9.61

Apparent specific gravity 2.273
Weight per cubic foot........................ 141.7 lbs.

LITTLETON STONE COMPANY.

From J. A. Connelly, Littleton, Wetzel County, West Virginia. Geological Horizon—Fish Creek Sandstone.

Ends were finished flat and were tested without plaster or other facing.

Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Tests.

Description	Dimensions			Sectional Area	First Crack	Ultimate Srength	
	Hgt.	Comp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Buff, (Brown)	3.89	3.88	3.88	15.05	112,200	122,000	8,110
Buff, (Brown)	3.72	3.80	3.80	14.44	89,000	97,000	6,720
Buff, (Brown)	3.86	3.87	3.87	14.98	119,800	119,800	8,000
Buff, (Brown)......	3.77	3.79	3.79	14.36	110,600	110,600	7,700
Buff, (Brown)......	3.85	3.85	3.85	14.82	105,000	105,000	7,090
Buff, (Brown)......	3.82	3.82	3.82	14.59	117,100	117,100	8,030
Gray, (Blue).......	3.82	3.82	3.81	14.55	197,200	197,200	13,550
Gray, (Blue).......	3.82	3.82	3.83	14.63	192,600	192,600	13,160
Grey, (Blue).......	3.83	3.82	3.82	14.59	205,000	206,000	14,120
Grey, (Blue).......	3.64	3.63	3.63	13.18	199,800	199,800	15,160
Grey, (Blue).......	3.65	3.65	3.65	13.32	111,200	111,200	8,350
Grey, (Blue).......	3.80	3.79	3.84	14.55	119,000	121,000	8,320
Grey, (Blue).......	3.78	3.81	3.81	14.52	119,200	119,200	8,210

Transverse Test—Gray Stone.
(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.00	3.85	20	840
5.98	3.85	20	850
5.80	3.90	20	1,718
Average			1,136

Transverse Test—Buff Stone.
(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
5.99	3.90	20	600
5.88	3.81	20	620
6.00	3.84	20	750
Average			657

Transverse Test.
(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.07	3.96	20	950
6.02	3.96	20	690
6.00	3.94	20	750
Average			797

Ratio of Absorption.
(U. S. Geological Survey.)

	Weight.			**Volume.**		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	1.48	2.82	2.87	3.77	7.20	7.33
	0.82	2.57	2.62	2.05	6.38	6.51
	1.27	2.64	2.64	3.15	6.57	6.57
Average	1.19	2.68	2.71	2.99	6.72	6.80

Apparent specific gravity........................ 2.509

Weight per cubic foot.............................. 156.4 lbs.

A. G. DAYTON SANDSTONE QUARRY.

From quarry owned by Hon. Arthur G. Dayton, Philippi, W. Va., Geological Horizon—Buffalo Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Test.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Conp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Buff	3.80	3.89	3.91	15.21	147,000	165,800	10,900
Buff	3.91	3.91	3.92	15.33	172,000	180,200	11,750
Buff	3.91	3.90	3.89	15.17	182,000	197,500	13,020
Buff	3.88	3.99	4.00	15.96	201,000	207,000	12,970
Buff	3.98	4.01	4.01	16.08	194,000	205,300	12,770
Buff	3.97	3.99	3.99	15.92	179,000	202,500	12,720

Transverse Test.

(U. S. Geological Survey).

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
5.77	4.03	20	570
5.85	4.00	20	850
5.50	4.02	20	780
Average			733

Transverse Test.

(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.00	4.03	20	730
5.90	4.05	20	1,240
5.95	3.98	20	730
Average			900

Ratio of Absorption.

(U. S. Geological Survey.)

	Weight. 30 min.	24 hours.	48 hours.	Volume. 30 min.	24 hours.	48 hours
	4.14	4.14	4.14	9.57	9.57	9.57
	4.16	4.16	4.16	9.63	9.63	9.63
	4.13	4.13	4.13	9.60	9.60	9.60
Average	4.14	4.14	4.14	9.60	9.60	9.60

Apparent specific gravity........................ 2.319
Weight per cubic foot......................... 144.6 lbs.

ALDERSON BROWNSTONE COMPANY.

From James D. Crump, near Alderson, West Virginia, Geological horizon—Mauch Chunk series. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown arsenal.

Description	Dimensions Hgt.	Comp'd Surface		Sectional Area	First Crack	Ultimate Strength Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Brown, (Red)......	3.85	3.90	3.90	15.21	356,000	356,000	23,410
Brown, (Red)......	3.94	3.96	3.98	15.76	299,000	392,500	24,900
Brown, (Red)......	3.96	3.97	3.98	15.80	374,000	375,500	23,770
Brown, (Red)......	3.97	3.98	3.97	15.80	371,000	373,000	23,610
Brown, (Red)......	3.90	3.96	3.95	15.64	258,000	258,000	16,500
Brown, (Red)......	3.96	3.98	3.98	15.84	354,500	354,500	22,380

Transverse Test.

(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.00	3.99	20	2,930
5.96	3.99	20	2,570
5.22	3.88	20	2,700

Average........................ 2,733

COMPRESSIVE ELASTIC PROPERTIES OF SANDSTONE.

The War Department at the Watertown Arsenal completed six tests on the West Virginia sandstones to determine compressive elastic properties. The description of these tests is given in the following paragraphs.

1. Samples for compressive elastic properties herewith reported were in the form of prisms measuring approximately 24 inches long by 4 inches by 6 in cross section dimensions. The samples were finished for testing on a rubbing bed. Compression observations were made by means of a compressometer covering a gauged length of 20 inches of the stone; this gauged length occupying a position equidistant from the ends of the sample. The samples were adjusted in the testing machine so that the loads were evenly distributed over the ends of the samples and an initial load of 100 pounds per square inch applied, at which time the reading of the compressometer was set at zero point. Loads were advanced with increments of 100 pounds per square inch. The compression of the stones was determined under each increment of load and the permanent sets determined by releasing the loads and returning to the initial load of 100 pounds. Loads were advanced in this way until a maximum was reached beyond which it did not seem prudent to pass. This maximum load was kept well within the ultimate resistance of the stone in order to preserve the sample for subsequent tests which have been requested by the survey.

2. The modulus of elasticity has been computed for each sample and for the sake of uniformity the same range of stress was used in each case. The range of stress chosen was from 1000 to 3000 pounds per square inch. In computing the modulus of elasticity, the permanent sets were deducted, that is, the value of the modulus depends upon the resilience of the material as here given. After the samples had been loaded with the higher loads, observations were made on their behavior over a lower range of stress. When these latter observations were made, the compression of the sample was observed under ascending stresses, and successive lengths

measured as the stone recovered in length under diminishing stresses. It will be noticed that the lengths of the samples were different under the same load according to whether the series of loadings was an ascending or a descending one, and furthermore that the rate of compressibility varied both under ascending and descending stresses. This behavior is common to softer stones.

3. The stones immediately respond to any change of stress whether loading or unloading and nearly the full amount of compression or resilience is immediately developed. Under sustained loads of a few minutes' duration a slight additional compression of the material occurs. Observations to show these features were made in the case of one of the samples herewith reported; the observations showing the behavior both under increasing and decreasing stresses. The development of early permanent set and their progressive increase was a feature generally shown by all the samples.

Compressive Elastic Properties.

Brown Sandstone from James D. Crump, Alderson, W. Va., Alderson Brownstone Co.

Weight, 50½ lbs. = 153.3 lbs. per cu. ft.

Length, 23.90″.

Sectional Area, 3.99″ x 5.97″ = 23.82 square inches.

Gauged Length, 20 inches.

Color, Brown. Tested at Watertown Arsenal.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq.″	Compress'n Inches	Set Inches	REMARKS
2,382	100	0.	0.	Initial load.
4,764	200	.0002	......	
7,146	300	.0006	......	
9,528	400	.0011	......	
11,910	500	.0015	0.	
14,292	600	.0021	......	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
16,674	700	.0027	......	
19,056	800	.0036	......	
21,438	900	.0042	......	
23,820	1,000	.0051	.0008	
35,730	1,500	.0091	......	
47,640	2,000	.0132	.0027	
59,550	2,500	.0176	......	
71,460	3,000	.0208	.0046	E (1000 to 3000)
83,370	3,500	.0242	......	3,361,000 lbs. per
95,280	4,000	.0278	.0060	sq. in.
....	.....	......	......	
....	200	.0063	......	
....	400	.0070	......	
....	800	.0090	......	
....	1,000	.0100	......	
....	1,500	.0135	......	
....	2,000	.0170	......	
....	1,500	.0146	......	
....	1,000	.0118	......	
....	800	.0105	......	
....	400	.0079	......	
....	200	.0066	.0061	
....	.....	......	......	
....	.....	......	......	Rested under 500 lbs.
....	100	......	.0056	per sq. in. 14
95,280	4,000	.0280	.0061	hours.
107,190	4,500	.0317	......	
119,100	5,000	.0351	.0073	
131,010	5,500	.0388	......	
142,920	6,000	.0421	.0088	
154,830	6,500	.0450	......	
166,740	7,000	.0480	.0101	
178,650	7,500	.0514	......	
190,560	8,000	.0542	.0115	
202,470	8,500	.0575	......	
214,380	9,000	.0608	.0127	
226,290	9,500	.0645	......	
238,200	10,000	.0677	.0144	
....	.....	......	.0141	Set after 2 min. rest.
....	.....	......	.0136	Set after 20 min. rest.
....	1,000	.0180	......	
....	2,000	.0238	......	
....	3,000	.0303	......	
....	4,000	.0365	......	
....	5,000	.0428	......	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
....	4,000	.0386	......	
....	3,000	.0337	......	
....	2,000	.0278	......	
....	1,000	.0212	.0141	
....	.....	......	......	
....	1,000	.0186	......	
....	2,000	.0246	......	
....	3,000	.0308	......	
....	4,000	.0370	......	
....	5,000	.0427	......	
....	6,000	.0473	......	
....	7,000	.0526	......	
....	8,000	.0577	......	
....	7,000	.0541	......	
....	6,000	.0501	......	
....	5,000	.0461	......	
....	4,000	.0418	......	
....	3,000	.0360	......	
....	2,000	.0296	......	
....	1,000	.0219	.0148	
....	.....	......	.0136	Set after resting 2 hours.
....	.....	......	......	
....	1,000	.0181	......	
....	2,000	.0240	......	
....	2,000	.0242	......	After 5 minutes.
....	3,000	.0305	......	
....	4,000	.0367	......	
....	4,000	.0371	......	After 5 minutes.
....	5,000	.0427	......	
....	6,000	.0476	......	
....	6,000	.0478	......	After 5 minutes.
....	6,000	.0480	......	After 10 minutes.
....	7,000	.0525	......	
....	8,000	.0577	......	
....	8,000	.0581	......	After 5 minutes.
....	8,000	.0582	......	After 10 minutes.
....	8,000	.0582	......	After 15 minutes.
....	8,000	.0582	......	After 20 minutes.
....	7,000	.0547	......	
....	6,000	.0507	......	
....	6,000	.0506	......	After 5 minutes.
....	6,000	.0506	......	After 10 minutes.
....	5,000	.0466	......	
....	4,000	.0423	......	
....	4,000	.0419	......	After 5 minutes.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
....	4,000	.0418	......	After 10 minutes.
....	3,000	.0366	......	
....	2,000	.0302	......	
....	2,000	.0298	......	After 5 minutes.
....	2,000	.0298	......	After 10 minutes.
....	1,000	.0227	......	
....	100	......	.0150	
....	100	......	.0145	After 5 minutes.
....	100	......	.0143	After 10 minutes.
....	100	......	.0143	After 15 minutes.
....	100	......	.0142	After 20 minutes.

Test discontinued.

HOOVER AND KINNEAR QUARRY.

From Hoover and Kinnear, Murrayville, West Virginia. Geological Horizon—Waynesburg Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Tests.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Buff	3.99	3.99	3.99	15.92	65,200	65,200	4,100
Buff	3.88	3.88	3.88	15.05	74,500	74,500	4,950
Buff	5.93	5.91	5.92	34.99	169,200	169,200	4,840
Buff	8.00	8.01	8.00	64.08	463,000	463,000	7,230

Transverse Test.

(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.00	4.02	20	880
6.05	3.94	20	580
5.95	3.99	20	790
Average.......................			750

Ratio of Absorption.

(U. S. Geological Survey.)

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours
	4.07	4.10	4.10	9.34	9.40	9.40
	4.55	4.61	4.61	10.83	10.97	10.97
	4.61	4.66	4.66	10.60	10.73	10.73
Average	4.41	4.46	4.46	10.26	10.37	10.37

Apparent specific gravity........................ 2.371

Weight per cubic foot......................... 147.8 lbs.

HUNDRED SANDSTONE QUARRY.

From W. H. Batson & Co., (formerly Mountain State Stone Co.) Hundred, W. Va. Geological Horizon—Dunkard Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Tests.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Buff	3.91	3.96	3.95	15.64	134,200	134,200	8,580
Buff	4.00	4.02	4.00	16.08	139,900	139,900	8,700
Buff	3.98	4.03	4.02	16.20	106,200	106,200	6,560
Buff	3.82	3.81	3.81	14.52	94,000	94,000	6,470
Buff	4.00	4.02	4.02	16.16	139,800	139,800	8,650
┼ x Buff	3.92	3.93	3.93	15.44	134,000	134,000	8,680

Transverse Test.

(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
5.95	3.99	20	680
5.85	3.94	20	920
5.87	3.94	20	860
Average			820

KINGS CREEK QUARRY COMPANY.

From King's Creek Quarry Company Geological Horizon—Lower Freeport Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Test.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Top L. Buff........	3.99	4.00	4.01	16.04	137,200	140,200	8,740
1st L. Gray........	3.96	3.99	3.98	15.88	217,500	217,500	13,700
1st L. Gray........	3.98	3.98	3.96	15.76	205,500	205,500	13,040
2nd L. Buff........	3.91	3.92	3.93	15.41	156,900	156,900	10,180

Transverse Test.

(U. S. Geological Survey).

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.00	4.00	20	990
6.01	3.86	20	860
5.97	3.87	20	1,640
Average			1,163

COAL AND COKE RAILROAD QUARRY.

From The Coal & Coke Railway, Charleston, West Virginia. Geological Horizon—Mahoning, Freeport Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Test.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Gray	3.81	3.81	3.79	14.44	169,800	169,800	11,760
Gray	3.79	3.79	3.79	14.36	170,400	170,400	11,870
Gray	3.96	3.95	3.96	15.64	198,700	198,700	12,700
Gray	3.78	3.78	3.78	14.29	200,200	200,200	14,010
Gray	3.90	3.90	3.91	15.25	179,600	179,600	11,780
Gray	3.88	3.89	3.89	15.13	187,400	187,400	12,390

Transverse Test.

(U. S. Geological Survey).

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.03	4.00	20	1,000
5.50	3.73	20	1,160
6.02	4.00	20	1,030

Average...................... 1,063

Compressive Elastic Properties.

Sandstone from the Coal & Coke Railway, Charleston, W. Va.

Weight, 45 lbs. = 151.6 lbs. per cu. ft.

Length, 23 x 85″.

Sectional Area, 3.74″ x 5.75″ = 21.51 square inches.

Gauged Length, 20 inches.

Color, Blue. Tested at Watertown Arsenal.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
2,151	100	0.	0.	Initial load.
4,302	200	.0010	.0004	
6,453	300	.0030	.0011	
8,604	400	.0050	.0020	
10,755	500	.0071	.0027	
12,906	600	.0093	.0036	
15,057	700	.0117	.0046	
17,208	800	.0141	.0053	
19,359	900	.0161	.0061	
21,510	1,000	.0183	.0068	
23,661	1,100	.0204	.0075	
25,812	1,200	.0222	.0081	
27,963	1,300	.0241	.0086	
30,114	1,400	.0261	.0094	
32,265	1,500	.0276	.0098	
34,416	1,600	.0293	.0103	
36,567	1,700	.0308	.0108	
38,718	1,800	.0323	.0112	
40,869	1,900	.0340	......	
43,020	2,000	.0350	.0114	
45,171	2,100	.0366	......	
47,322	2,200	.0378	......	
49,473	2,300	.0390	......	
51,624	2,400	.0401	......	
53,775	2,500	.0413	.0132	
55,926	2,600	.0428	......	
58,077	2,700	.0439	......	
60,228	2,800	.0449	......	
62,379	2,900	.0458	......	
64,530	3,000	.0469	.0145	E (1000 to 3000)
66,681	3,100	.0481	......	1,914,000 lbs. per
68,832	3,200	.0490	......	sq. in.
70,983	3,300	.0499	......	
73,134	3,400	.0508	......	
75,285	3,500	.0518	.0155	

Test discontinued.

GASSAWAY SANDSTONE QUARRY.

From The Coal & Coke Railway, Gassaway, West Virginia. Geological Horizon—Morgantown Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Tests.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Dark buff, Coarse grain	3.55	3.81	3.81	14.52	101,400	101,400	6,980
Dark buff, Coarse grain	3.93	3.98	3.97	15.80	141,000	141,000	8,920
Green, Fine grain	3.95	3.93	3.93	15.44	193,700	193,700	12,550
Green, Fine grain	3.89	3.93	3.92	15.41	192,400	192,400	12,490
Gray, Fine grain	3.96	3.99	4.00	15.96	129,900	129,900	8,140
Gray, Fine grain	3.92	3.92	3.93	15.41	121,900	121,900	7,910

Transverse Test.

(U. S. Geological Survey).

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.01	4.01	20	900
5.88	3.97	20	1,390
5.92	4.02	20	690
Average			993

FRAMETOWN SANDSTONE QUARRY.

From Simmons & Company, Frametown, Braxton County, W. Va. Geological Horizon—Buffalo—Mahoning Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Tests.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per Sq In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Buff	3.88	3.88	3.88	15.05	98,600	98,600	6,550
Buff	4.00	4.00	3.99	15.96	105,000	105,000	6,580

Transverse Test.

(U. S. Geological Survey).

Breadth.	Depth.	Span.	Modulus of Rupture.
Inches.	*Inches.*	*Inches.*	*Pounds.*
6.00	4.00	20	650
5.75	4.00	20	570
Average			610

Compressive Elastic Properties.

Sandstone from Simmons & Company, Frametown, Braxton County, W. Va.

Weight, 43¾ lbs. = 138.4 lbs. per cu. ft.

Length, 23" x 75".

Sectional Area, 4." x 5.75" = 23 square inches.

Gauged Length, 20 inches.

Color, Brown. Tested at Watertown Arsenal.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
2,300	100	0.	0.	Initial load.
4,600	200	.0031	.0018	
6,900	300	.0061	.0033	
9,200	400	.0089	.0045	
11,500	500	.0118	.0057	
13,800	600	.0141	.0067	
16,100	700	.0163	.0076	
18,400	800	.0186	.0084	
20,700	900	.0207	.0091	
23,000	1,000	.0225	.0099	
25,300	1,100	.0243	.0103	
27,600	1,200	.0260	.0107	
29,900	1,300	.0278	.0113	
32,200	1,400	.0294	.0120	
34,500	1,500	.0310	.0124	
36,800	1,600	.0326	.0131	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
39,100	1,700	.0341	.0134	
41,400	1,800	.0355	.0138	
43,700	1,900	.0369	.0143	
46,000	2,000	.0384	.0147	
48,300	2,100	.0397	......	
50,600	2,200	.0406	......	
52,900	2,300	.0418	......	
55,200	2,400	.0431	......	
57,500	2,500	.0441	.0156	
59,800	2,600	.0456	......	
62,100	2,700	.0468	......	
64,400	2,800	.0477	......	
66,700	2,900	.0489	......	
69,000	3,000	.0498	.0165	E (1000 to 3000) 1,932,000 lbs. per sq. in.
71,300	3,100	.0514	......	
73,600	3,200	.0523	......	
75,900	3,300	.0533	......	
78,200	3,400	.0542	......	
80,500	3,500	.0552	.0177	
....	.....	......	......	
....	200	.0192	......	
....	400	.0229	......	
....	600	.0262	......	
....	800	.0290	......	
....	1,000	.0316	......	
....	1,200	.0340	......	
....	1,400	.0363	......	
....	1,600	.0384	......	
....	1,800	.0404	......	
....	2,000	.0424	......	
....	1,800	.0411	......	
....	1,600	.0396	......	
....	1,400	.0379	......	
....	1,200	.0361	......	
....	1,000	.0340	......	
....	800	.0316	......	
....	600	.0289	......	
....	400	.0255	......	
....	200	.0210	.0178	

Test discontinued.

GEORGES' CREEK COAL AND IRON COMPANY.

From George's Creek Coal & Iron Company. Geological Horizon—Waynesburg Sandstone. Ends were finished flat and were tested without plaster or other facing. Samples prepared by finishing on a rubbing bed, and tested at Watertown Arsenal.

Compression Tests.

Description	Dimensions			Sectional Area	First Crack	Ultimate Strength	
	Hgt.	Comp'd Surface				Total	Per Sq. In.
	Ins.	Ins.	Ins.	Sq. in.	Lbs.	Lbs.	Lbs.
Buff, Fine grained..	3.75	3.77	3.79	14.20	128,000	128,600	9,000
Buff, Fine grained..	3.76	3.78	3.73	14.10	135,200	135,200	9,590
Buff, Fine grained..	3.73	3.78	3.74	14.14	105,000	125,400	8,870
Buff, Coarse grained.	3.91	3.89	3.87	15.05	119,800	119,800	7,960
Buff, Coarse grained	3.81	3.88	3.87	15.02	117,400	117,400	7,820
Buff, Coarse grained.	3.85	3.84	3.87	14.86	122,000	122,000	8,270
Gray	3.77	3.82	3.86	14.75	169,700	169,700	11,510
Gray	3.88	3.96	3.93	15.56	181,000	181,000	11,630
Gray	3.90	3.93	3.96	15.56	163,000	170,900	10,980
Gray	3.97	3.93	3.94	15.48	149,000	165,700	10,700
Gray	3.94	3.94	3.95	15.56	164,500	164,500	10,570
Gray	3.90	3.93	3.91	15.37	161,600	161,600	10,510

Transverse Test. Buff Stone.

(U. S. Geological Survey).

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.05	3.87	20	770
5.98	3.95	20	890
5.91	4.00	20	810
Average......................			823

Transverse Test, Gray Stone.

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.00	3.98	20	1,150
6.00	3.90	20	1,040
6.03	3.96	20	910
Average....................			1,033

Transverse Test.

(U. S. Geological Survey.)

Breadth.	Depth.	Span.	Modulus of Rupture.
Inches.	*Inches.*	*Inches.*	*Pounds.*
6.00	4.00	20	940
5.90	4.00	20	910
5.95	4.00	20	830
Average			893

Ratio of Absorption.

(U. S. Geological Survey.)

	Weight.			Volume.		
	30 min.	24 hours.	48 hours.	30 min.	24 hours.	48 hours.
	4.22	4.25	4.25	9.79	9.87	9.87
	4.08	4.20	4.20	9.51	9.78	9.78
	3.91	4.02	4.02	9.12	9.37	9.37
Average	4.07	4.16	4.16	9.44	9.64	9.64

Apparent specific gravity........................ 2.328
Weight per cubic foot.......................... 145.1 lbs.

Compressive Elastic Properties.

BROWN SANDSTONE from George's Creek Coal & Iron Company, Underwood, W. Va.

Weight, 45¼ lbs. = 138.7 lbs. per cu. ft.

Length, 23.80″.

Sectional Area, 3.96″ x 5.98″ = 23.68 square inches.

Gauged Length, 20 inches.

Color, Brown. Tested at Watertown Arsenal.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
2,368	100	0.	......	Initial load.
4,736	200	.0015	.0005	
7,104	300	.0027	.0010	
9,472	400	.0043	.0015	
11,840	500	.0058	.0019	
14,208	600	.0073	.0024	
16,576	700	.0088	.0028	
18,944	800	.0102	.0032	
21,312	900	.0116	.0036	
23,680	1,000	.0131	.0039	
26,048	1,100	.0142	.0043	
28,416	1,200	.0155	.0045	
30,784	1,300	.0169	.0049	
33,152	1,400	.0181	.0051	
35,520	1,500	.0190	.0052	
37,888	1,600	.0202	.0055	
40,256	1,700	.0214	.0058	
42,624	1,800	.0226	.0061	
44,992	1,900	.0236	......	
47,360	2,000	.0248	.0065	
49,728	2,100	.0257	......	
52,096	2,200	.0267	......	
54,464	2,300	.0276	......	
56,832	2,400	.0286	......	
59,200	2,500	.0296	.0075	
61,568	2,600	.0308	......	
63,936	2,700	.0319	......	
66,304	2,800	.0326	......	
68,672	2,900	.0335	......	
71,040	3,000	.0344	.0085	E (1000 to 3000) 2,395,000 lbs. per sq. in.
73,408	3,100	.0356	......	
75,776	3,200	.0364	......	
78,144	3,300	.0372	......	
80,512	3,400	.0381	......	
82,880	3,500	.0390	.0094	
85,248	3,600	.0402	......	
87,616	3,700	.0410	......	
89,984	3,800	.0418	......	
92,352	3,900	.0428	......	
94,720	4,000	.0436	.0103	
....	200	.0112	......	
....	400	.0134	......	
....	600	.0157	......	
....	800	.0180	......	
....	1,000	.0202	......	
....	1,200	.0221	......	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
....	1,400	.0240	......	
....	1,600	.0258	......	
....	1,800	.0276	......	
....	2,000	.0292	......	
....	1,800	.0279	......	
....	1,600	.0266	......	
....	1,400	.0251	......	
....	1,200	.0236	......	
....	1,000	.0219	......	
....	800	.0199	......	
....	600	.0177	......	
....	400	.0151	....	
....	200	.0119	.0104	

Test discontinued.

BLUE SANDSTONE from Georges Creek Coal & Iron Company, Underwood, W. Va.

Weight, 47¾ lbs. = 143.9 lbs. per cu. ft.

Length, 23.95".

Sectional Area, 3.97" x 6.03" = 23.94 square inches.

Gauged Length, 20 inches.

Color, Blue. Tested at Watertown Arsenal.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
2,394	100	0.	0.	Initial load.
4,788	200	.0017	.0006	
7,182	300	.0040	.0015	
9,576	400	.0064	.0026	
11,970	500	.0088	.0036	
14,364	600	.0110	.0045	
16,758	700	.0133	.0055	
19,152	800	.0152	.0060	
21,546	900	.0171	.0070	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
23,940	1,000	.0186	.0073	
26,334	1,100	.0203	.0077	
28,728	1,200	.0219	.0084	
31,122	1,300	.0233	.0088	
33,516	1,400	.0247	.0094	
35,910	1,500	.0263	.0098	
38,304	1,600	.0272	.0100	
40,698	1,700	.0283	.0102	
43,092	1,800	.0294	.0107	
45,486	1,900	.0306	......	
47,880	2,000	.0315	.0112	.0100 Set after resting 40 hours.
50,274	2,100	.0311	......	
52,668	2,200	.0320	......	
55,062	2,300	.0327	......	
57,456	2,400	.0335	......	
59,850	2,500	.0346	.0111	
62,244	2,600	.0356	......	
64,638	2,700	.0364	......	
67,032	2,800	.0373	......	
69,426	2,900	.0381	......	
71,820	3,000	.0389	.0118	E (1000 to 3000) 2,532,000 lbs. per sq. in.
74,214	3,100	.0400	......	
76,608	3,200	.0407	......	
79,002	3,300	.0413	......	
81,396	3,400	.0421	......	
83,790	3,500	.0431	.0127	
86,184	3,600	.0440	......	
88,578	3,700	.0447	......	
90,972	3,800	.0454	......	
93,366	3,900	.0461	......	
95,760	4,000	.0468	.0134	
....	200	.0143	......	
....	400	.0168	......	
....	600	.0195	......	
....	800	.0217	......	
....	1,000	.0239	......	
....	1,200	.0259	......	
....	1,400	.0278	......	
....	1,600	.0297	......	
....	1,800	.0313	......	
....	2,000	.0329	......	
....	1,800	.0318	......	
....	1,600	.0305	......	
....	1,400	.0291	......	
....	1,200	.0276	......	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
....	1,000	.0259	......	
....	800	.0240	......	
....	600	.0218	......	
....	400	.0190	......	
....	200	.0157	......	.0136

Test discontinued.

MERRICK SANDSTONE QUARRY.

From C. D. Merrick, Parkersburg, West Virginia. Geological Horizon—Marietta Sandstone. Ends were finished flat and were tested without plaster or other facing. Tested at Watertown Arsenal. Samples prepared by finishing on a rubbing bed.

Compression Tests.

Dimensions			Sectional Area	First Crack	Ultimate Strength	
Height	Compressed Surface				Total	Per Sq. In.
Inches	Inches	Inches	Per Sq In	Pounds	Pounds	Pounds
3.97	3.98	4.00	15.92	127,300	132,400	8,320
3.95	4.00	4.00	16.00	86,500	89,900	5,620
3.99	4.00	4.05	16.20	95,500	99,700	6,150
4.00	4.00	4.03	16.12	89,100	91,300	5,660

Pyramidal fractures.

Compressive Elastic Properties.

Sample from C. D. Merrick Quarry operated by J. P. Whealdon, Parkersburg, W. Va.

Weight, 47¼ lbs. = 142.4 lbs. per cu. ft.

Length, 23.92".

Sectional Area, 3.98" x 6.02" = 23.96 square inches.

Gauged Length, 20 inches.

Color, Blue. Tested at Watertown Arsenal.

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
2,396	100	0.	0.	Initial load.
4,792	200	.0017	......	
7,188	300	.0042	.0019	
9,584	400	.0071	.0029	
11,980	500	.0097	.0038	
14,376	600	.0126	.0051	
16,772	700	.0154	.0059	
19,168	800	.0179	.0070	
21,564	900	.0202	.0076	
23,960	1,000	.0219	.0085	
26,356	1,100	.0219	.0092	
28,752	1,200	.0257	.0096	
31,148	1,300	.0275	.0102	
33,544	1,400	.0293	.0108	
35,940	1,500	.0310	.0113	
38,336	1,600	.0325	.0117	
40,732	1,700	.0343	.0121	
43,128	1,800	.0362	.0125	
45,524	1,900	.0374	.0130	
47,920	2,000	.0391	.0131	
50,316	2,100	.0407	.0135	
52,712	2,200	.0423	.0140	
55,108	2,300	.0437	.0145	
57,504	2,400	.0450	.0149	
59,900	2,500	.0462	.0152	
....	.....	......	.0149	Set after 2 min. rest.
....	.....	......	......	
....	200	.0161	......	
....	400	.0191	......	
....	600	.0221	......	
....	800	.0252	......	
....	1,000	.0282	......	
....	1,200	.0311	......	
....	1,400	.0338	......	
....	1,600	.0361	......	
....	1,800	.0386	......	
....	2,000	.0411	......	
....	1,800	.0397	......	
....	1,600	.0381	......	
....	1,400	.0363	......	
....	1,200	.0343	......	
....	1,000	.0320	......	
....	800	.0295	......	
....	600	.0261	......	
....	400	.0226	......	
....	200	.0181	.0154	

APPLIED LOADS		IN GAUGED LENGTH		
Total Lbs.	Lbs. Per Sq."	Compress'n Inches	Set Inches	REMARKS
....	.....	......	.0152	After 2 min. rest.
62,296	2,600	.0472	.0154	Rested under initial
64,692	2,700	.0483	.0160	road 1 hour.
67,088	2,800	.0499	.0163	
69,484	2,900	.0512	.0167	
71,880	3,000	.0526	.0169	E (1000 to 3000)
74,276	3,100	.0541	.0173	1,794,000 lbs. per
76,672	3,200	.0553	.0177	sq. in.
79,068	3,300	.0569	.0179	
81,464	3,400	.0583	.0181	
83,860	2,500	.0593	.0184	
....	200	.0195	......	
....	400	.0222	......	
....	800	.0292	......	
....	1,200	.0352	......	
....	1,600	.0406	......	
....	2,000	.0451	......	
....	1,600	.0425	......	
....	1,200	.0379	......	
....	800	.0326	......	
....	400	.0259	......	
....	200	.0212	.0186	

Test discontinued. Prism not ruptured.

Transverse Test.

(U. S. Geological Survey.)

Breadth. *Inches.*	Depth. *Inches.*	Span. *Inches.*	Modulus of Rupture. *Pounds.*
6.01	3.88	20	780
5.90	3.86	20	830
5.97	3.98	20	broken

Average........................ 805

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